INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

28066

1861.

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81 Newhall Street, Birmingham.

1861.

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1861.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

LIFE MEMBERS.

1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. Maudslay, Henry, Club Chambers, 15 Regent Street, London, S.W.
1848. Penn, John, The Cedars, Lee, Kent, S.E.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allen, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, Edward Ellis, 5 Parliament Street, Westminster, S.W.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Courtney Stephens and Co., Blackall Place Iron Works, Dublin.
1858. Appleby, Charles Edward, Mining Engineer, 39 Mornington Road, Regent's Park, London, N.W.
1861. Armitage, Harry W., Farnley Iron Works, Leeds.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1857. Armstrong, Joseph, Great Western Railway, Locomotive Department Wolverhampton.

1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1848. Baker, William, London and North Western Railway, Euston Station, London, N.W.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Bordesley Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Parkgate Iron Works, Rotherham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1860. Beck, Richard. Lister Works, Upper Holloway, London, N.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Works, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F, Messrs. Beyer Peacock and Co., Gorton, near Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.
1858. Bouch, William, Shildon Engine Works, Darlington.
1847. Bovill, George Hinton, Durnsford Lodge, Wandsworth, Surrey, S.W.
1858. Bower, John Wilkes, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1854. Bragge, William, Atlas Street Works, Sheffield.
1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.
1856. Bray, Edwin, Nevill Holt, near Market Harborough.
1861. Brierly, Henry, 19 Grosvenor Square, Lower Broughton, Manchester.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, John, Atlas Steel Works, Sheffield.

1855. Brown, John, Mining Engineer, Barnsley.
1856. Brown, John, Mining Engineer, Bank Top, Darlington.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1858. Burn, Henry, Locomotive Superintendent, Danube and Black Sea Railway Kustendjie, near Varna.
1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds,
1859. Butler. John, Old Foundry, Stanningley, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, Midland Great Western Railway. Dublin.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel Works, Sheffield.
1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1856. Carrett, William Elliott, Sun Foundry, Leeds.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1849. Chamberlain, Humphrey, Yarmouth, Isle of Wight.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesborough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay : (or care of T. D. Hornby, Exchange Buildings, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1860. Cowie, David, Engine Works, Abo, Finland.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1853. Craig, William Grindley, 14 Cannon Street, London, E.C.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.

1857. Criswick, Theophilus, Plymouth Iron Works, Merthyr Tydvil.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, Engineer, West Hetton Collieries, near Ferryhill.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Dodds, Thomas W., Holmes Engine Works, Rotherham.
1857. Douglas, George K., Resident Engineer, Birkenhead Railway, Birkenhead.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1859. Egleston, Thomas, Jun., 10 Fifth Avenue, New York, United States.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, New Cross, Surrey, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 224 Gresham House, Old Broad Street, London, E.C.
1861. Fearnley, Thomas, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Midland Railway, Locomotive Department, Derby.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.
1847. Fothergill, Benjamin, 65 Cannon Street, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, Resident Engineer, Leeds Bradford and Halifax Junction Railway, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., Phœnix Works, Wakefield.
1858. Greenwood, Thomas, Albion Foundry, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1857. Hall, William, Bloomfield Iron Works, Tipton.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, Pontypool Iron Works, Pontypool.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1859. Head, Jeremiah, Walnut Tree Cottage, Battersea Rise, Wandsworth, London, S.W.
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1858. Hedley, John, Resident Engineer, South Hetton Colliery, near Fence Houses.
1848. Hewitson, William Watson, Airedale Foundry, Leeds.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesborough.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, Altrincham Street, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Horsley, William, Jun., Hartley Engine Works, Seaton Sluice, near North Shields.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1847. Howell, Joseph, Hawarden Iron Works, Holywell, Flintshire.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1861. Huffam, Frederick Thomas, Messrs. Slaughter Gruning and Co., Avonside Iron Works, Bristol.
1857. Humber, William, Pancras Chambers, Pancras Lane, Bucklersbury, London, E.C.
1859. Hunt, James P., Corngreaves Iron Works, Congreaves, near Birmingham.
1856. Hunt, Thomas, London and North Western Railway, Locomotive Department, Crewe.
1860. Hurry, Henry C., Engineer, West Midland Railway, Worcester.

1850. Ikin, Jonathan Dickson, 18 Great George Street, Westminster, S.W.
1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.

1860. Jackson, Samuel, Cyclops Steel Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Street Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1847. Jobson, Robert, Dudley.
1847. Johnson, James, Great Northern Railway, Locomotive Department, Doncaster.
1848. Johnson, Richard William, Oldbury Carriage Works, near Birmingham.
1861. Johnson, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1849. Johnson, William, 166 Buchanan Street, Glasgow.
1855. Johnson, William Beckett, St. George's Iron Works, Hulme, Manchester.
1861. Jones, Alfred, Herbert's Park Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Messrs. C. De Bergue and Co., Strangeways Iron Works, Manchester.

1857. Kay, James Clarkson, Phœnix Foundry, Bury. Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near North Shields.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway ; 10 Liverpool Street, New Broad Street, London, E.C.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1859 Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.

1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, Suffolk Works, Berkley Street, Birmingham.

1860. Lee, John, Victoria Foundry, Litchurch, near Derby.
1857. Lees, Sylvester, Locomotive Superintendent, East Lancashire Railway, Bury, Lancashire.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Beehive Mills, Thornton Road, Bradford, Yorkshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Jun., Old Park Iron Works, Wednesbury.
1856 Longridge, Robert Bewick, Steam Boiler Assurance Company, New Brown Street, Market Street, Manchester.
1859. Lord, Thomas Wilks, 32 Boar Lane, Leeds.
1861. Low, George, Messrs. Williamson Brothers, Canal Iron Works, Kendal.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Midland Railway, Derby.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, Stourbridge.
1860. Marten, George Priestley, Messrs. Stothert and Marten, Steam Ship Works, Bristol.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, Spon Lane Glass Works, near Birmingham.
1853. Matthews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn & Co. Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 35 Ely Place, Holborn, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Beypoor: (or care of E. J. Burgess, 8 Austin Friars, London, E.C.)
1847. McClean, John Robinson, 17 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.

1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1853. Miller, George Mackey, Great Southern and Western Railway, Dublin.
1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, Melrose Cottage, Plumstead Common, near Woolwich, S.E.
1861. Mitchell, Joseph, Worsbro' Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1857. Muntz, George Frederick, French Walls, near Birmingham.
1856. Muntz, George Henri Marc, Albion Tube Works, Nile Street, Birmingham.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, Vulcan Foundry, Glasgow.
1861. Natorp, Gustavus, Messrs. Naylor Vickers and Co., Don Steel Works, Sheffield.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1858. Nichol, Peter Dale, East Indian Railway, Locomotive Department, Howrah, Calcutta : (or care of Anthony Nichol, Quay Side, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, London and North Western Railway, Engineer's Office, Liverpool.

1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
1847. Owen, William, Messrs. Sandford and Owen, Phœnix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1858. Parkinson, John, Victoria Brass and Copper Works, Bury, Lancashire.
1847. Peacock, Richard, Messrs. Beyer Peacock & Co., Gorton, near Manchester.
1848. Pearson, John, 1 Manchester Buildings, Old Hall Street, Liverpool.
1859. Peet, Henry, Lancaster and Carlisle Railway, Locomotive Department, Carlisle.
1861. Perkins, Loftus, 6 Francis Street, Regent's Square, London, W.C.

1856. Perring, John Shae, 104 King Street, Manchester.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., Eccleston Hall, near Prescot.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.
1859. Platt, John, Hartford Iron Works, Oldham.
1861. Plum, Thomas William, Blaenavon Iron Works, near Newport, Monmouthshire.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, West Midland Railway, Worcester
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1855. Prideaux, Thomas Symes, 32 Charing Cross, London, S.W.

1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1859. Rennie, George Banks, 39 Wilton Crescent, Belgrave Square, London, S.W.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1858. Robson, Jonathan, Blackwall Engine and Iron Ship Building Works, Gateshead.
1852. Rofe, Henry, Engineer, Birmingham Water Works, Paradise Street, Birmingham.
1851. Rogers, Ebenezer, Abercarn, near Newport, Monmouthshire.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Salford, Manchester.
1860. Rumble, Thomas William, Atlas Steel Works, Sheffield.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1859. Ryder, John Northcote, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 28 Cornhill, London, E.C.

1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George G., Parkgate Iron Works, Rotherham.
1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1858. Scott, Joseph, Messrs R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1848. Scott, Michael, 26 Parliament Street, Westminster, S.W.
1861. Scott, Walter Henry, London and North Western Railway, Locomotive Department, Wolverton.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1847. Sinclair, Robert, Eastern Counties Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Atherstone.
1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.
1853. Slaughter, Edward, Avonside Iron Works, Bristol.
1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.
1854. Smith, George, Wellington Road, Dudley.
1847. Smith, Henry, Spring Hill Works, Birmingham.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1858. Smith, Isaac, 36 Lancaster Street, Birmingham.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.
1859. Smith, Matthew, Fazeley Street Wire Mills, Birmingham.
1860. Smith, Richard, The Priory, Dudley.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1857. Snowdon, Thomas, Stockton-on-Tees.
1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopgate Street, London, E.C.)
1859. Spencer, John Frederic, Bank Buildings, Newcastle-on-Tyne.
1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1857. Stokes, Lingard, Locomotive Superintendent, East Indian Railway, Howrah, Calcutta.
1861. Sumner, William, 36 Faulkner Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cathcart Street, Birkenhead.
1860. Thierry, Eugène, Inspecting Engineer, Russian Railways, 25 Place Vendôme, Paris.
1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1858. Thomson, William, Jun., Railway Foundry, Normanton.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway' Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department Chester.
1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.
1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.
1856. Waddington, Thomas, New Dock Iron Works, Leeds.
1861. Walker, John G., Netherton Iron Works, near Dudley.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Iron Works, Burton-on-Trent.
1847. Weallens, William, Messrs. R. Stephenson and Co., South Stree Newcastle-on-Tync.

1860. Weild, William, Messrs. Beyer Peacock & Co., Gorton, near Manchester.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.
1847. Whitworth, Joseph, Chorlton Street, Manchester.
1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay, 69 Cornhill, London, E.C.
1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, Manchester Sheffield and Lincolnshire Railway, Engineer's Office, London Road, Manchester.
1856. Wilson, Edward, West Midland Railway, Worcester.
1858. Wilson, Edward Brown, 36 Parliament Street, Westminster, S.W.
1859. Wilson, George, Messrs. Cammell and Co., Cyclops Steel Works, Sheffield.
1857. Wilson, John, Spring Works, Hill Top, Westbromwich.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 27 Duke Street, Westminster, S.W.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Midland Road, Derby.
1861. Woodhouse, William Henry, 23 Parliament Street, Westminster, S.W.
1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Lancaster.
1859. Wright, Joseph, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Works, Tipton Green, Dudley.
1859. Wrigley, Francis, Queen's Chambers, 5 Market Street, Manchester.
1853. Wymer, Francis W., Tyne and Continental Steam Navigation Company, Newcastle-on-Tyne.

1861. Yule, William, Baird's Works, St. Petersburg.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.
1858. Budden, William Humphryes, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.

1848. Crosby, Samuel, Leek Street, Birmingham.
1850. Gwyther, Edwin, Belmont Row, Birmingham.
1857. Hawkes, William, Eagle Foundry, Broad Street, Birmingham.
1860. Hutchinson, William, West Hartlepool.
1858. Lawton, Benjamin C., Grainger Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)
1860. Manby, Cordy, New Street, Dudley.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1859. Sherriff, Alexander Clunes, General Manager, West Midland Railway, Worcester.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1861. Williamson, Alexander W., Ph.D., University College, Gower Street, London, W.C.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1851. Potts, John Thorpe, 4 Crescent Place, The Grove, Camberwell, Surrey, S.

COUNCIL, 1861.

President.

SIR WILLIAM G. ARMSTRONG,	Newcastle-on-Tyne.

Vice-Presidents.

ALEXANDER B. COCHRANE,	Dudley.
JAMES FENTON,	Low Moor.
HENRY MAUDSLAY,	London.
JOHN PENN,	London.
JOHN RAMSBOTTOM,	Crewe.
JOSEPH WHITWORTH,	Manchester.

Council.

ALEXANDER ALLAN,	Perth.
JOHN ANDERSON,	Woolwich.
CHARLES F. BEYER,	Manchester.
WILLIAM E. CARRETT,	Leeds.
EDWARD A. COWPER,	London.
JOHN FERNIE,	Derby.
ROBERT HAWTHORN,	Newcastle-on-Tyne.
EDWARD JONES,	Wednesbury.
JAMES KITSON,	Leeds.
SAMPSON LLOYD,	Wednesbury.
WALTER MAY,	Birmingham.
C. WILLIAM SIEMENS,	London.
WILLIAM WEALLENS,	Newcastle-on-Tyne.
EDWARD WILSON,	Worcester.
NICHOLAS WOOD,	Hetton.

Treasurer.

HENRY EDMUNDS,
Birmingham and Midland Bank, Birmingham.

Secretary.

WILLIAM P. MARSHALL,
Institution of Mechanical Engineers,
81 *Newhall Street, Birmingham.*

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PROCEEDINGS.

31 January, 1861.

The Fourteenth Annual General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 31st January, 1861 : Benjamin Fothergill, Esq., Vice-President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.
1861.

The Council have much pleasure, on this the Fourteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory position and progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1860, shows a balance in the Treasurer's hands of £1109 2*s.* 11*d.*, after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1860, and report that the following balance sheet rendered by the Treasurer is correct.

(See Balance Sheet appended.)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 428, of whom 18 are Honorary Members, and 2 are Graduates : 8 are Life Members, 4 of whom have been added during the past year.

The following deceases of Members of the Institution have occurred during the past year 1860:—

Charles Cowper, ...	London.
William B. B. Harvey, . .	Calcutta.
Charles May, ...	London.
Joseph Miller, ...	Carlisle.
Robert B. Preston, . . .	Liverpool.
Robert Russel, ...	Londonderry.
Frank W. S. West, . . .	Calcutta.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished.

LIST OF DONATIONS TO THE LIBRARY.

Collection of Engineering Drawings, third part; from the École Impériale des Ponts et Chaussées.

Portrait of Robert Stephenson; from his executors.

Third Report of the Commissioner on the Internal Communications of New South Wales; from Capt. Martindale, R.E.

Report on Railway Works and Railway Extension Contracts in New South Wales; from Capt. Martindale, R.E.

Report of the Commissioner of Patents, United States, 1857 and 1858.

Transactions of the Institution of Civil Engineers of Ireland, from the commencement; from the Institution.

Reports of the Royal Cornwall Polytechnic Society; from the Society.

Journal of the Royal United Service Institution, from the commencement; from the Institution.

Reports of the Association for the Prevention of Steam Boiler Explosions; from Mr. H. W. Harman.

Useful Information for Engineers (second series), by William Fairbairn; from the author.

Elements of Mechanism, by T. M. Goodeve; from the author.

Steam on Common Roads, by C. F. T. Young; from the author.

On the Working and Ventilation of Coal Mines in Northumberland and Durham, by Mr. John Wales; from the author.

Steam Boiler Explosions, by Zerah Colburn; from the author.

On the Thermo-dynamics of Elastic Fluids, by Joseph Gill; from the author.

The Screw Propeller, by Robert Wilson; from the author.

Proceedings of the Institution of Civil Engineers; from the Institution.

Reports of the British Association for the Advancement of Science; from the Association.

Transactions of the French Institution of Civil Engineers; from the Institution.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Royal Scottish Society of Arts; from the Society.

Memoirs of the Literary and Philosophical Society of Manchester; from the Society.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

The Mechanics' Magazine; from the Editor.

The Civil Engineer and Architect's Journal; from the Editor.

The London Journal of Arts; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

Original Drawings of Boulton and Watt's Pumping Engine; from Mr. William D. Burlinson.

Photographs of Westminster New Bridge Works; from Mr. Alexander B. Cochrane and Mr. John Cochrane.

Photograph of Locomotive Boiler; from Mr. George Alton.

Specimens of Ironstone; from Mr. Samuel H. Blackwell.

Specimens of Puddled Bar and Rail made from Cleveland Pig Iron; from Mr. Thomas Snowdon.

Specimen of Railway Chair and Key; from Mr. Edgar Gilkes.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position,

by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

Description of an improved Gas Meter; by Mr. Alexander Allan, of Perth.

On the application of Superheated Steam; by Mr. John N. Ryder, of London.

On Giffard's Injector for feeding steam boilers; by Mr. John Robinson, of Manchester.

On some Regenerative Hot-Blast Stoves, working at a temperature of 1300° Fahrenheit; by Mr. Edward A. Cowper, of London.

On Pinel's Magnetic Water Gauge for steam boilers; by Mr. George Piggott, of Birmingham.

On the Ten Yard Coal of South Staffordshire and the mode of Working; by Mr. William Mathews, of Dudley.

Description of a method of Taking Off the Waste Gases from Blast Furnaces; by Mr. Charles Cochrane, of Middlesborough.

Description of a Machine for Covering Telegraph Wires with India-rubber; by Mr. C. William Siemens, of London.

On the Burning of Coal instead of Coke in Locomotive Engines; by Mr. Charles Markham, of Derby.

Description of Aerts' Water Axlebox; by Mr. Sampson Lloyd, of Wednesbury.

On a new process of Open Coking; by Mr. Samuel H. Blackwell, of Dudley.

Description of a Machine for Drilling instead of Punching wrought iron plates; by Mr. John Cochrane, of Dudley.

Description of the Round Oak Ironworks; by Mr. Frederick Smith, of Brierley Hill.

On the application of the Decimal System of Measurement in Boring and Turning Wheels and Axles; by Mr. John Fernie, of Derby.

Description of Machinery for Crushing Stone for macadamising roads; by Mr. Charles G. Mountain, of Birmingham.

On Taking Off the Waste Gas from Open-Topped Blast Furnaces; by Mr. Samuel Lloyd, of Wednesbury.

Description of a new Safety Coupling for Railway Wagons; by Mr. Charles Markham, of Derby.

Description of a Steam Hammer for Light Forgings; by Mr. Richard Peacock, of Manchester.

The Council have particular pleasure in referring to the great success attending the Annual Provincial Meeting of the Institution in Birmingham last summer, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. Walter May, for the excellent reception that was given to the Members of the Institution on that occasion; and they look forward with much confidence to the important advantages arising from the continuance of these Annual Provincial Meetings, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—

injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines — comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.

Blast Engines, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage — different constructions of engines, double-cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm-governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

Caloric Engines—engines worked by Gas, or explosive compounds—Electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

Sugar Mills, particulars of construction and working—results of the application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to the construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

Wood-working Machines, morticing, planing, rounding, and surfacing—copying machinery.

Lathes, Planing, Boring, Drilling, and Slotting Machines, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

Rolling Mills, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction, and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.

WATER PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

AIR PUMPS, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

ROTARY AND CENTRIFUGAL PUMPS,	ditto	ditto	ditto
FIRE ENGINES, hand and steam,	ditto	ditto	ditto
SLUICES AND SLUICE COCKS, worked by hand or hydraulic power,			ditto

CRANES, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

DECIMAL MEASUREMENT, application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of various Bodies, facts relating to friction under ordinary circumstances —facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels —water meters, construction and working.

Well Sinking, and Artesian Wells, facts relating to—boring tools, construction and mode of using.

Tunnelling Machines, particulars of construction and results of working.

Coffer Dams and Piling, facts relating to the construction—cast iron sheet piling.

Piers, fixed and floating, and pontoons, ditto ditto

Pile Driving Apparatus, particulars of improvements—use of steam power —particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

Dredging Machines, particulars of improvements—application of dredging machines—power required and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Lighthouses, cast iron and wrought iron, ditto ditto

Ships, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

Mining Operations, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials — safety guides — winding machinery — underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

Blast Furnaces, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Converting Furnaces, construction of furnaces — manufacture of steel — casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Smiths' Fans, and Fans generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.

Railways, construction of permanent way — section of rails, and mode of manufacture — mode of testing rails — experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements — engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction — self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers — different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December*, 1860.

Cr.	£	s.	d.
By Balance 31st December, 1859	713	16	11
,, Subscriptions from 26 Members in arrear	78	0	0
,, ditto from 359 Members for 1860	1077	0	0
,, ditto from 4 Members in advance for 1861	12	0	0
,, ditto from 4 Life Members	120	0	0
,, ditto from 2 Graduates for 1860	4	0	0
,, Entrance Fees from 57 New Members	114	0	0
,, Sale of Extra Reports	17	19	6
,, Interest from Bank	21	11	11
	£2158	8	4

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	356	4	6			
Less Authors' copies of papers, repaid	39	8	6	316	16	0
,, Stationery and Printing				65	1	7
,, Office Expenses and Petty Disbursements				32	2	3
,, Expenses of Meetings				16	1	6
,, Fittings, Furniture, and Repairs				6	6	5
,, Travelling Expenses				5	9	6
,, Parcels				3	8	8
,, Postages				35	12	0
,, Salaries				450	0	0
,, Rent and Taxes				118	7	6
,, Balance 31st December, 1860				1109	2	11
				£2158	8	4

(Signed) EDWARD JONES, SAMPSON LLOYD, } Finance Committee.

31*st January*, 1861.

The CHAIRMAN moved that the Report of the Council be received and adopted, which was passed: he congratulated the Members on the flourishing position and successful progress of the Institution, and thought it was highly gratifying to see the continued increase in the number of Members and in the prosperity of the Institution.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

ALEXANDER B. COCHRANE,	Dudley.
JAMES FENTON,	Low Moor.
HENRY MAUDSLAY,	London.
JOHN PENN,	London.
JOHN RAMSBOTTOM,	Crewe.
JOSEPH WHITWORTH,	Manchester.

COUNCIL.

JOHN ANDERSON,	Woolwich.
CHARLES F. BEYER,	Manchester.
ROBERT HAWTHORN,	Newcastle-on-Tyne.
JAMES KITSON,	Leeds.
WALTER MAY,	Birmingham.
WILLIAM WEALLENS,	Newcastle-on-Tyne.

Members of Council remaining in office.

ALEXANDER ALLAN,	Perth.
WILLIAM E. CARRETT,	Leeds.
EDWARD A. COWPER,	London.
JOHN FERNIE,	Derby.
EDWARD JONES,	Wednesbury.
SAMPSON LLOYD,	Wednesbury.
C. WILLIAM SIEMENS,	London.
EDWARD WILSON,	Worcester.
NICHOLAS WOOD,	Hetton.

TREASURER.

Henry Edmunds,	. . .	Birmingham.

SECRETARY.

William P. Marshall,	. .	Birmingham.

The following New Members were also elected :—

MEMBERS.

Charles Denton Abel,	. .	London.
Harry W. Armitage,	. .	Leeds.
Henry Brierly,	. . .	Manchester.
Charles Dutton,	. . .	Westbromwich.
Daniel Joseph Fleetwood,	.	Birmingham.
Edward Forster,	. . .	Westbromwich.
Alfred Jones,	. . . .	Bilston.
Robert Charles May,	. .	London.
Robert Porter,	. . .	Birmingham.
George G. Sanderson,	. .	Rotherham.
James Tangye,	. . . .	Birmingham.
John G. Walker,	. . .	Dudley.

HONORARY MEMBER.

Charles Ratcliff,	. . .	Birmingham.

The following paper was then read :—

DESCRIPTION OF THE BUDA WROUGHT-IRON LIGHTHOUSE.

By Mr. JOHN H. PORTER, of Birmingham.

The small map accompanying the drawings of the Buda Wrought Iron Lighthouse, Fig. 2, Plate 2, represents the outline of the land near the mouths of the river Ebro on the eastern coast of Spain. It will be seen that by the peculiarity of the outline of this portion of the coast two natural harbours of refuge are formed; that lying to the north is called Fangal, and that to the south Alfaques. Midway between these the river Ebro flows in two channels to the sea. Dividing these two channels of the Ebro, and formed mainly by the detritus brought down by its waters, lies the flat delta called the island of Buda.

The almost unvarying level of the Mediterranean is here bounded by a coast so flat as to offer but slight landmarks for the guidance of mariners seeking the mouths of the Ebro or the harbours of Fangal and Alfaques. The Spanish government have determined to erect in this locality three lighthouses: a leading or principal light of the second order upon the north eastern extremity of the island of Buda, as shown on the map; a light of the third order upon the point of Bana covering the harbour of Alfaques; and one of the sixth order upon the point of Fangal protecting the harbour of that name. The two smaller are fixed lights, while that of the Buda lighthouse is a revolving light visible at a distance of twenty miles and producing bright flashes at intervals of a minute. The lighting apparatus together with the lanterns and light rooms for these lighthouses are being manufactured by Messrs. Chance, who have kindly furnished the writer with some details of their construction, that this description of the Buda lighthouse may be the more complete. The general designs for these lighthouses were furnished by Don Lucio del Vallé,

of the corps of Royal Engineers of Spain; and the details of the construction submitted by the writer for his approval were referred to the Direction of Public Works in Spain for their sanction.

The Buda lighthouse will be erected on the margin of the sea, not actually in the water, but so close that in very stormy weather its base may be washed by the sea and spray. Owing to the sandy nature of the ground Mitchell's screw piles are adopted for the foundation: eight of them are arranged in an octagon of 56 feet diameter and a ninth is placed in the centre. Upon the top of the piles, starting at about 3 feet above the level of the sea, is an octagonal pyramidal structure of open ironwork, 150 feet high from the top of the piles to the level of the lantern platform at the summit, as shown in the general elevation, Fig. 1, Plate 1.

From the centre pile rises a hollow cast iron column to a height of 31 feet, from which point radiate the beams that support the platform of the dome-shaped dwelling house. To protect this platform from the violence of the wind, which might otherwise act with great force upon its under surface, an inverted cone is constructed beneath, serving also as a receptacle for stores. This cone was suggested by a similar arrangement adopted in the construction of the small screw-pile lighthouses on our own coasts, such as the Maplin Sand lighthouse near the mouth of the Thames, erected about twenty years ago. From the house platform, rising through the dome to the lantern platform at the summit, is a wrought iron cylindrical tower enclosing the winding staircase by which the keepers ascend to the light.

From the eight external piles rise eight wrought iron pillars, converging from an octagon of 56 feet diameter at the base to one of 9 feet 10 inches diameter at the summit. The nine supports are united horizontally at ten points in the height of the structure by sets of horizontal framing adapted for resisting compression or extension, the intersection of which with the uprights forms thus a series of quadrilateral spaces in the sides of the octagonal pyramid; and these spaces are crossed diagonally by round tie rods, which are united in a centre ring to admit of being screwed up to a state of tension. Other

tie rods radiate obliquely from the central tower to the external uprights, each fitted with a right and left handed screw coupling, and are attached to the tower midway between the tiers of horizontal framing; eight of them ascend and eight descend to the junctions of the framings with the corner pillars. The eight ascending rods thus form in connexion with the horizontal framing under compression a system of trussing analogous to that commonly employed in the interior of gasholders, and so distribute their portion of the central load upon the external supports. By this arrangement the weight of the central tower and stairs is sustained at intervals in the height of the structure by the eight corner pillars, and but slightly by the dome or by the centre pile. The sets of eight descending rods assist with other portions of the structure in preventing any distortion of the general fabric.

The total weight of the superstructure including the lantern is about 170 tons; of which about 40 tons are upon the centre pile, leaving from 16 to 17 tons to be borne by each of the eight corner piles. The ground in which the foundations have to be placed is indeed a sandbank which is gradually extending itself seawards; and although there are the most satisfactory proofs of the sustaining or resisting powers of the screw piles under similar circumstances, it was thought well to have ample margin for contingencies; and while making the superstructure as light as possible, consistently with a due regard to stability, to secure by means of a maximum of screw surface and strength of pile a safeguard against inequalities in the density of the sand. The sustaining power of the screw piles in a foundation of sand has been found to be equal in tons to six times the square of the diameter of the screw in feet; and it is considered that a load in tons of at least five times the square of the diameter in feet can with perfect safety be placed upon a screw pile under such circumstances. This in the case of a screw of 4 feet diameter amounts to 80 tons.

For the Buda lighthouse the screws are 4 feet diameter, and are fixed upon piles of 8 inches diameter entering 30 feet into the sand, as shown in Fig. 1, Plate 1, and enlarged in Figs. 9 and 12, Plate 3. The piles A are solid, of hammered iron, forged in one length; the

upper ends, Fig. 11, are reduced to 7 inches diameter for a length of 22 inches, at which point a collar is welded to the body of the 8 inch pile, on which rests the cast iron cap B. Figs. 8 to 11, Plate 3, show the mode in which the wrought iron corner pillars C are stepped upon the pile caps B in connexion with the horizontal framing of girders D at the base.

The arrangement of the horizontal framing of girders at the base is shown in plan by the diagram, Fig. 3, Plate 2: Fig. 28, Plate 6, shows an enlarged section of the girders that radiate from the centre and of those that form the sides of the octagon; and Fig. 29 is a section of the bracing girders which are framed between the larger girders and form the inner octagons. The girders having no load to sustain are made with but small sectional area in their upper and lower flanges. Depth was considered of importance, as affording surface for rivetting or bolting to the flanges of the corner pillars, and as securing a rigid framework at the base, which, together with the superincumbent weight thus immoveably imposed, should prevent any lateral stress upon the piles. Moreover these systems of rigid horizontal framing tend, in conjunction with the several pillars they are so completely connected with, to relieve any single pile which from an unexpected weakness in its foundation of sand might stand in need of such assistance: a contingency however scarcely to be supposed probable, when the dimensions of the screw and the comparative insignificance of the load are considered. The girders of the base are of puddled steel, manufactured by the Mersey Steel and Iron Company, which it is believed will be less affected by corrosion from the action of the sea water and atmosphere than ordinary iron; and since, with a view to rigidity in this framework of girders, considerable surface occurs, it has been thought desirable to employ a material of closer texture and more highly carbonised than ordinary wrought iron; the more so, because with it is obtained also a superior strength and toughness.

The connexion of the radiating girders of this framing with the centre pile cap and with the cast iron column springing from it is shown in Figs. 13 and 15, Plate 4, and enlarged in Figs. 21 and 22, Plate 5, which refer also to the connexion of corresponding girders in

the succeeding stage of horizontal framing, from which springs the base of the cone below the house platform. The junctions of the cast iron column are all bored, turned, and faced in the lathe.

Although in the only other structure of this nature at all comparable in point of dimensions, namely the screw-pile lighthouse erected by the government of the United States upon the Florida Reef, the principal supports consist of cast iron tubes, it was considered that wrought iron was preferable for the pillars of the Buda lighthouse. It was thought that for such a purpose there was an insecurity in so brittle a material as cast iron; that it was less fitted to undergo the vibration or tremor which occasionally and perhaps to a certain extent generally will pervade a structure of this character and of these dimensions: added to which was a consideration of the inconvenience that would result from the breakage of any of the cast iron tubes in transit, in trans-shipment, or in erection abroad. Wrought iron was therefore determined upon, and next came the consideration of the best form in which to employ it. The tubular form, whether circular or angular, was considered to have a disadvantage in not affording the means of protecting the interior surface of the iron tube from corrosion. It was not considered an economical form in construction for such dimensions as the circumstances seemed to require. The connexions of the several lengths of a pillar with each other and with the horizontal and other framing seemed to be attended with more expense and less simplicity in detail than was desirable. The solid circular form was not open to the first of these objections: on the contrary it presented a minimum of surface for exposure to oxidation and for the wind to act upon, both points of advantage. But the weight of the material as an element in the cost, considering the dimensions that would have been necessary, would have been a maximum, and the price of the bars per ton considerably beyond that of ordinary sizes of bars or plates: and no method of connecting the several lengths seemed economical enough to counterbalance the effect of the first cost of the bars. The actual expense so far would however have been considered comparatively unimportant in the face of the

two advantages already cited; but beyond the desiderata of immunity from oxidation and a minimum of exposure to the wind, one of equal importance was that of convenient surfaces for the attachment in an immoveably rigid manner of the series of horizontal frames, as well as simplicity of connexion for the tension bars of the exterior and centre. The provision of these essential points with a solid bar of at least some 5 or 6 inches diameter seemed attended with considerable expense: clips and collars, as employed in structures upon a smaller scale, being considered insufficient.

The form shown in the enlarged sections, Figs. 25 and 26, Plate 6, produced by rivetting an obtuse-angled angle iron on either side of a wide flat bar, seemed to combine simplicity and economy in the manufacture and in the longitudinal connexions, with lateral stiffness in the pillar itself and with the desired facility of rigid connexion with the other portions of the structure. This form was ultimately adopted in preference to the solid circular form shown in Fig. 27. The angle formed by the two angle irons rivetted to the flat bar corresponds with the angle of the octagon; thus while the centre bar presents a convenient and substantial connexion for the radiating girders, the side flanges afford in like manner a convenient and rigid attachment for those of the octagonal frames.

The larger section of pillar, Fig. 25, Plate 6, consists of a bar 12 inches by 1 inch, with angle irons of 4 inches by 5 inches and $\frac{3}{4}$ inch thick united to it by 1 inch rivets spaced 6 inches apart. This section is carried up to a height of 5 feet above the level of the house platform, from which point the smaller section is employed, as shown in Fig. 26. This differs from the former only in the centre bar, which is reduced to 9 inches in width. There is thus no portion of the pillar of a less thickness than $\frac{3}{4}$ inch, and all parts of it can be conveniently inspected after erection, and carefully scraped and repainted when necessary. The surface exposed to the wind is insignificant considering the bracing of the fabric generally. The flanged structure of the pillar itself contributes greatly to its stiffness in all directions, while its sectional area of 24 square inches in the lower portion and 21 square inches in the upper is far more than necessary for resisting the forces that compress it in the direction of

its length. The connexion of the several lengths of the pillar is very simple: the angle irons break joint 6 feet, passing respectively 3 feet above and below the meeting of the ends of the centre bar, and cover plates 3 feet long are used at the junctions of the angle irons and of the centre bar.

The mode of attachment of the horizontal girders to the corner pillars is shown in Figs. 17 to 20, Plate 5, in two different stages of horizontal framing. Figs. 17 and 18 show the attachment in the second stage of horizontal framing, midway between the base and the house platform, the arrangement of the girders being similar to that shown in the diagram, Fig. 3, Plate 2. Figs. 19 and 20 show the attachment immediately above the house dome, where the arrangement of the framing is as shown in the plan, Fig. 4. Similar arrangements of horizontal framing are adopted for the succeeding stages above, with slight modifications as the diameters lessen; Fig. 5 representing the smallest, at the top. Enlarged sections of the bars that compose these frames are given in Figs. 34 to 40, Plate 6: Figs. 34 to 37 corresponding with the plan, Fig. 4, Plate 2, above the house platform; and Figs. 38 to 40 with the plan, Fig. 5, at the top. The curved braces that surround the central staircase tower in the horizontal framework are of angle iron, Figs. 37 and 40, Plate 6, as are also those that connect the radiating beams with the exterior octagonal frame.

Fig. 6, Plate 2, is a diagram of the arrangement of the girders in the house platform, enlarged sections of which are given in Figs. 31 to 33, Plate 6. Fig. 31 is a section of the radiating girders, the connexion of which with the top of the cast iron centre column is shown in Figs. 13 and 14, Plate 4. Fig. 32 is a section of the girders connecting the eight corner pillars and receiving the ends of the intermediate radiating girders. Fig. 33 is a section of the girder at the base of the dome, having the web plate carried up above the level of the platform for the purpose of excluding from the floor of the house the rain water that will fall upon the platform without. Fig. 30 is a section of one of the ribs of the house dome.

The reasons for adopting the dome form for the dwelling house were that the eight ribs of the dome, braced by horizontal framing between and by the radiating beams of an upper floor, assist in sustaining and transferring to the corner pillars a portion of the weight of the central staircase tower and stairs, which otherwise would augment the load upon the centre pile. The dome also presents a small amount of surface in any one plane for the wind to act upon ; and is a form well fitted to resist a shock : it admits of the attachment of stays or braces between the ribs and the corner pillars of the lighthouse, as shown in Fig. 1, Plate 1, in such a way as to constitute with the radiating beams of the upper floor a system of horizontal bracing, which contributes to the support of the corner pillars and of the dome itself. Between the ribs of the dome horizontal purlins of iron and timber receive the external covering of corrugated galvanized iron and the inner lining of match boarding, a space of 4 inches being left between the two as a non-conductor. At the crown of the dome and surrounding the staircase tower a raised skylight fitted with moveable louvre boards, Fig. 1, admits light to the small upper rooms and affords ventilation, with an exit for the air that in hot weather may become heated between the inner and outer covering ; this heated air will the more rapidly pass away, as small apertures near the base of the dome give admission to a cooler draught. The cone beneath the house consists of eight ribs E, Fig. 13, Plate 4, of $\frac{3}{8}$ inch plate 8 inches wide with angle irons rivetted to its edge of a suitable angle for the octagonal form ; eight intermediate ribs of T iron 3 inches by 6 inches are placed between, and the spaces are filled by plate iron $\frac{3}{16}$ inch thick, stiffened with horizontal angle irons. Within this cone, upon a set-off F cast upon the central column, a wrought plate iron ring receives small joists of angle iron G in pairs, rivetted at their outer extremities to the principal ribs of the cone ; and between these joist bars are fitted light chequered plates of cast iron to form a flooring.

From the house platform immediately above the cast iron centre column rises the cylindrical tower, $6\frac{1}{2}$ feet diameter, containing the circular stairs, Fig. 1, Plate 1. It is constructed of plate iron $\frac{1}{4}$ inch

thick, and above the dome of the house the plates are 8 feet 2 inches in length, placed vertically, two such lengths corresponding to the distance of 16 feet 4 inches from centre to centre of the successive stages of horizontal framing. Six plates in width form the circumference of the cylinder. The edges of the plates are butted on all sides, with cover strips on the exterior: those covering the horizontal joints are 6 inches wide by $\frac{5}{8}$ inch thick, and those of the vertical joints 4 inches by $\frac{3}{8}$ inch. Figs. 23 and 24, Plate 5, show the attachment of the horizontal radiating girders to the staircase tower, and the eight ribs of the house dome are connected to it by a similar attachment. The circular or winding stairs within the tower are of cast iron, the risers and treads in distinct castings, each having an eye or ring socketing into the other, and strung upon a central tube of wrought iron 2 inches diameter: the outer sides of the treads are bolted to the plating of the tower by four $\frac{1}{2}$ inch bolts and nuts. At every revolution of the stairs a double tread or landing occurs; and in the three upper landings, at a distance of 2 feet 7 inches from the centre, apertures of 6 inches diameter are made for the descent of the weight connected with the clockwork of the lighting apparatus.

The lighting apparatus is fixed upon a pedestal exactly over the centre of the staircase tower, and its weight being considerable is supported by four plate iron beams of 15 inches depth passing right across, rivetted by angle plates to the tower, and secured at their outer extremities between the angle irons of the external corner pillars. The diagram plan, Fig. 7, Plate 2, shows the arrangement of the principal framing of the lantern platform. The curved lines within the angles of the four radiating beams at the centre represent the upper angle irons diverted from the webs for the purpose of stiffening this portion of the work, and with the addition of a wrought iron plate rivetted over all, as shown by the dotted lines, providing a support for the pedestal of the light. Four short beams of the same depth also connect the tower with the four remaining corner pillars. The angle irons of these eight beams are continued outwards beyond the corner pillars to an octagon frame of 18 feet diameter, which with the open wrought iron railing

surmounting it forms the boundary of the lantern platform, as shown in Fig. 1, Plate 1. The portion of the platform extending beyond the eight corner pillars is supported by eight curved T iron brackets, Fig. 1, strongly connected between the angle irons of the pillars. The flooring of the lantern platform is of wrought iron chequered plates $\frac{5}{16}$ inch thick, rivetted down upon the radiating beams, upon the horizontal octagonal framing, and upon an angle iron ring that surrounds the upper edge of the staircase tower.

On the lantern platform is the light room, Fig. 1, Plate 1, 7 feet high, composed of twelve cast iron panels. On the top of these panels is fixed a cast iron soleplate which projects about 12 inches on the outside all round, forming a narrow path for the convenience of the light keepers in cleaning the lantern. The lantern is 8 feet high and composed of twelve gun-metal stanchions bearing a gun-metal cornice, upon which is placed a double dome of copper fixed upon eight gun-metal rafters. The lighting apparatus is a revolving light of the dioptric kind, commonly known as Fresnel's system; and is of the size known as the second order.

Referring to the general construction and details of the lighthouse as now described, it has to be remarked that in addition to a rigid connexion of all parts of the structure it was necessary to have regard to simplicity, convenience, and safety in the process of erecting abroad. With this object the jointing of the several lengths of the external corner pillars is arranged so as to admit of each stage or tier of horizontal framework being permanently attached to the pillars at a distance of 5 feet below the centres of their joints. The lower angle iron coverplate is thereby some 6 inches clear above the horizontal framing, each stage of which thus affords, with the addition of some scaffold boards, a most secure and convenient platform to place the materials on for proceeding with the erection of the succeeding lengths of the external pillars and central tower. The junctions of these parts of the structure can there be conveniently rivetted and bolted, the diagonal tie rods attached and their degree of tension adjusted with accuracy. This self-contained substantial scaffolding is found to be one of the most satisfactory features in the

design; and the central staircase tower being raised in cylinders of 8 feet 2 inches length, answering to a complete revolution of the stairs, and two such lengths corresponding exactly with the spacing of each tier of framing and ties above the house dome, a permanent and secure means of ascending and descending is provided as the work proceeds: the small window openings admitting at the same time of a man passing through the side of the tower to the platform of framing next below it. This special advantage will moreover always exist for the inspection of all parts of the structure, affording the same convenience for painting when occasion requires.

Mr. Porter observed that in the general appearance of the lighthouse the cone under the house platform might perhaps convey the idea of concentrating the weight of the structure upon the centre pile; but this was not the case, the sole object of the conical form being to break the upward force of wind underneath the flooring, and the ribs of the cone were simply to stiffen the plates of which it was composed. Even the central tower containing the staircase was only partially carried by the centre pile, the weight being mainly transferred to the eight outside pillars of the lighthouse by the diagonal trussing at each of the horizontal framings; and by this mode of construction there was abundant sustaining power for carrying the entire weight of the staircase tower, even if the centre pile were removed.

Mr. J. Fenton observed that the main horizontal beams in each course of framing appeared to be constructed in the form of girders, though described as merely ties between the corner pillars; and he enquired what was the reason for adopting the girder form, instead of a simple tube with a bolt through it, which he thought would have been the direct mode of resisting the strain of both compression and tension to which they were exposed.

Mr. Porter said the horizontal beams were not girders really, as there was no load upon them, but were merely struts and ties between the corner pillars; but the girder form of construction, as shown in the drawings, was adopted for convenience of make, and because it

afforded room for convenient attachment to the other parts of the framing by rivetting. The depth obtained by the girder form had also the advantage of adding to the diagonal stiffness of each face of the lighthouse, by increasing the rigidity of the junctions with the corner pillars: and the radiating girders in each tier of horizontal framing were also made of the same deep form, to increase the resistance to transverse vibration.

Mr. E. A. Cowper had been concerned in the construction of several wrought iron lighthouses of smaller size, amongst others the Mucking and Sea Reach lighthouses near the mouth of the Thames, made at Messrs. Fox Henderson and Co.'s works, in which the corner pillars were hollow cylinders of wrought iron, about 10 inches diameter, constructed of $\frac{3}{4}$ inch plates bent round and rivetted together with a butt joint. That made a neat looking construction, but it was certainly expensive, and almost impossible to paint inside: in the construction now described the entire surface was exposed to view and accessible for painting. He thought the section of the main pillars seemed rather light, considering the great height of the structure; probably some metal might have been spared out of the horizontal framings and added in the pillars with advantage.

The diagonal bracing was a most excellent system, and an essential provision in such a construction. The Maplin Sand lighthouse was originally designed without diagonal stays; but when erected it was found that, though strong enough vertically, the whole rocked and twisted round horizontally when a moderate force was exerted at the top of any one of the pillars at regular intervals, so as to get into time with the vibration of the structure; such a motion might have proved fatal to its stability, and diagonal stays were therefore added, as in the lighthouse now described, which entirely corrected the defect. He thought the screw piles would prove a valuable means of conveniently obtaining a good foundation in sand; but would have preferred however a strong heavy cast iron sill at the bottom, bedded in a mass of concrete, for the pillars to stand in, with the addition of strong diagonal braces starting from the sill. In the Bishop's Rock lighthouse near the Land's End, constructed of a framework with cast iron corner pillars, there was no diagonal bracing for the first

12 feet high, so that in a storm shortly after it was erected the whole lighthouse had twisted round and the pillars broke off at the base. A stone lighthouse was now being built in its place at a greatly increased cost, whereas the original iron structure might have been made thoroughly satisfactory and secure, if it had been properly stiffened with diagonal stays starting from the very foundation.

Mr. J. Cochrane thought there was not any better system of bracing than that shown in the drawings, in which it appeared to be well carried out; but he would prefer to have it begin from the very bottom, by the addition of diagonal braces between the piles, as had been suggested. The Sydenham water towers were constructed in a similar manner, only that instead of horizontal bracing a horizontal wrought iron diaphragm or annular plate 3 feet wide was fixed at each tier between the joints of the columns, which served to stiffen the whole structure, and vertical diagonal bracing was used as well. He enquired what saving of metal was effected by the use of puddled steel instead of iron in the lowest tier of the lighthouse.

Mr. Porter replied that the weight was about 25 or 30 per cent. less with the puddled steel than it would have been with iron, for the same strength. The foundation piles rose only about 3 feet above the surface of the ground, and then the lowest tier of horizontal framing had the effect of staying the heads of the piles and preventing any racking or twisting, so that it had not appeared necessary to add any diagonal bracing between the piles.

Mr. A. Masselin thought the construction of the framing was rather too light for so high a structure, and there would be a considerable vibration at the top: he had felt even stone lighthouses vibrate in a gale more than was pleasant, and feared the effect of the wind would be greater in the present instance, with a heavy weight on the top of such a high and light tower. The highest iron lighthouse previously erected that he knew of was only 112 feet high, but this was 150 feet high; and the weight of the lantern and apparatus at the top would be fully 10 tons, which he thought would produce a great tremor on all the joints in a storm of wind, having a tendency to make it insecure after some years' exposure. Although not erected actually in the water, the lighthouse was so near the shore as to be within reach of

the water in a gale; and there might be a possibility of a wreck or a piece of timber being carried against one of the horizontal struts or one of the corner pillars, and breaking it by the violence of the blow, when there would be imminent danger for the whole structure. He fully concurred in the importance of the diagonal tie rods, but thought they were rather small in section, being only $1\frac{1}{4}$ and 1 inch diameter; and if a few were to give way from corrosion or otherwise, he feared the remainder would suffer.

For the lantern platform at top he thought an inverted cone was as desirable as for the house platform at bottom, to break the upward force of the wind; and this would also improve the appearance by making it look less slender at the top. The lantern or light room was a 12 sided figure, with alternate large sides about $3\frac{1}{2}$ feet wide by 7 feet high, thus presenting a large surface for the wind to act upon.

Mr. F. J. Bramwell remarked that the stiffness of the mode of construction adopted in the lighthouse was shown by the experience of the Crumlin viaduct in South Wales, which was 200 feet high with a number of spans of 150 feet each, the railway being carried on four Warren's truss girders: the piers were built of slender cast iron columns with diagonal bracing, of so light a construction that they appeared at first more like temporary scaffolding than permanent piers, and the appearance of the lighthouse closely resembled them. The weight of the girders and the passage of trains on the viaduct must produce as great a stress upon the piers, he thought, as the lantern would on the top of the lighthouse of only three quarters the height, and the action of the wind would be the same in both cases; but the viaduct had stood secure since first erected several years ago, and therefore he did not see any cause for alarm in the slender appearance of the lighthouse. The only material difference that he noticed was that the piers at Crumlin were fixed on the solid rock, instead of on piles sunk in sand.

Mr. C. Markham considered the Crumlin viaduct was not an analogous case to the lighthouse, but differed from the latter in having the piers all tied together longitudinally by the girders resting on the top of them, which effectually prevented any vibration of the piers

under the rolling motion of the trains; whereas the lighthouse was an isolated tower, carrying a heavy weight at a great height without being steadied by any extraneous support.

Mr. F. J. Bramwell observed that although the piers in the Crumlin viaduct were strengthened in the longitudinal direction by the girders at top, these did not afford any aid in sustaining them laterally; and in this direction therefore the piers were in as exposed a condition as the lighthouse, being subjected to the full action of the wind when blowing up or down the valley crossed by the viaduct, while the girders at top presented so much additional surface to the wind.

Mr. J. Fernie enquired how the several lengths of the main corner pillars in the lighthouse were connected together at the junctions, so as not to cause any diminution of strength at those parts.

Mr. Porter replied that the joint of one of the angle irons composing the pillar was made 3 feet below the joint of the middle plate, and that of the other angle iron 3 feet above; cover plates 3 feet long were added on the face of each angle iron at the joints, and a pair of the same length at the joint of the middle plate, making the joints as strong as the rest of the pillar. There was now about 100 feet height erected at the works, which the members would be able to see on the following day.

The Chairman thought the paper was one of much interest and value, describing the practical application of open wrought iron work in a structure of such importance and magnitude. In connexion with this subject he hoped they might be able to obtain a paper on the mechanical arrangements adopted at the present time in the lighting of lighthouses. He proposed a vote of thanks to Mr. Porter for his paper, which was passed.*

The following paper, communicated through Mr. Edward Jones of Wednesbury, was then read :—

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* Since the meeting, and in consequence of the suggestion then made in the discussion, a horizontal framing of wrought iron girders has been added, fixed to the piles at 3 feet below the surface of the sand, and similar in construction to that at the tops of the piles.

ON BENSON'S HIGH-PRESSURE STEAM BOILER.

By Mr. JOHN JAMES RUSSELL, of Wednesbury.

The boiler forming the subject of the present paper, the invention of Mr. Martin Benson of Cincinnati, U.S., was described at a former meeting of the Institution, in a paper giving the particulars of the application and working of a number of these boilers in America, where they have been in operation from three to four years and about 50 of them are in use for various purposes. (See Proceedings Inst. M. E., Nov. 1859.)

A boiler of this construction having since been erected at the writer's works at Wednesbury, and having now worked satisfactorily for ten months, the further results are given in the present paper. This boiler has been in constant work during the whole of the time with entire success, driving an engine of 60 indicated horse power; and the writer has been so thoroughly satisfied with the results and the correctness of the principle upon which the boiler is constructed that he has since erected a second and larger one upon the same plan, but with some improvements in the details of construction, results of experience derived from the former boiler. This boiler is now at work on the same premises, and is shown in Figs. 1, 2, and 3, Plate 7. Fig. 1 is a front elevation, showing the receiver and circulating pump; Fig. 2 is a longitudinal section of the boiler, and Fig. 3 a transverse section at right angles to Fig. 2.

The boiler proper is composed entirely of tubes A, Fig. 2, arranged in a series of horizontal rows over the fire. BB are doorways at the front and back of the boiler for fixing, disconnecting, and taking out the tubes. C, Fig. 1, is the water and steam receiver: D the circulating pump, which draws its supply of water from the receiver C and is worked by the small donkey engine E above. F is the main

supply pipe from the circulating pump, to which the lowest tubes of each section of the boiler are connected. G is the main delivery pipe, to which the top tubes of each section are joined, and into which the water and steam together are delivered from the tubes and thence discharged into the upper part of the receiver C.

The circulating pump D is shown enlarged in Fig. 10, Plate 9, and is a simple direct-acting pump with a metallic packed piston, constructed with a single slide valve H instead of suction and delivery valves, so that it is certain and constant in its action; the slide valve is made without any lap or lead, and thus agrees exactly with the motion of the piston. The pump draws its supply of water from the receiver through the ordinary exhaust port I running round the cylinder, and discharges it by the outlet pipe K, forcing it into the tubes through the pipe F, Fig. 1. The steam generated in the tubes is driven up with the water through the tubes and discharged through the pipe G into the receiver C, where the steam and water are separated; and the water is then again taken by the circulating pump and returned into the tubes. In starting the boiler the receiver is supplied with water until its level reaches the fifth or sixth row of tubes from the bottom, as shown by the dotted line in Fig. 1; as the circulating pump is standing still at first in consequence of having no steam to work it, the slide valve H, Fig. 10, is allowed to be lifted off its face by the pressure of the water, and lets the water flow past the pump direct through into the tubes. The fire is then lighted and steam raised from the water in the tubes, which starts the circulating pump to work.

More water is forced through the tubes by the circulating pump than is evaporated in them. The circulating pump of the boiler now used for ten months is double-acting, 6 inches in diameter with 9 inches stroke, and makes 40 revolutions per minute against a resistance of from 7 to 10 lbs. pressure per square inch; the power required to work it is therefore about $\frac{1}{2}$ horse power including the friction of the pump. At this speed it forces through the boiler from 9 to 11 times as much water as is evaporated, which has been found too much to get the greatest efficiency of the boiler; and from 6 to 8 times the quantity evaporated is considered about the proper proportion. In

this instance owing to the construction of the donkey engine the pump cannot be worked at less than 40 revolutions per minute, at which speed it is fully capable of supplying a 100 horse power boiler at ordinary working pressures, instead of one of only 60 horse power. With high pressure steam superheated and worked expansively, the pump is large enough for a 150 horse power boiler, in which case $\frac{1}{3}$rd per cent. or $\frac{1}{300}$th of the whole power produced is all that is required for working the circulating pump; and with the improved circular bends that have now been adopted for uniting the ends of the tubes in the boiler there is reason to expect the circulation can be maintained with much less power. No more power is required to work the pump with 80 and 100 lbs. steam than with 20 lbs., since the pressure is the same on both sides of the piston and the only resistance to be overcome is the friction of the water in the tubes, which of course is increased in proportion to the speed; with the boiler now at work the resistance on the piston at the proper speed does not exceed 7 to 10 lbs. per square inch. Originally the delivery pipe G, Fig. 2, into which the steam and water from the tubes are discharged, was only 5 inches diameter inside, which was found too small; in the present boiler it has been made 10 inches diameter. The receiver C is supplied with feed water by one of Giffard's injectors L, Fig. 1, instead of an ordinary feed pump.

It was originally supposed that the mechanical circulation of the water with 9 to 11 times more water forced through the tubes than is evaporated would be sufficient to prevent deposit, by keeping them washed out clean; and this is the case to a certain extent, as all loose matter is washed by the circulation from the tubes into the receiver. Some incrustation however does take place, but not sufficient to present any practical difficulty or cause any damage to the tubes. One of the tubes from the first boiler is exhibited as a specimen, showing the amount of deposit that has been formed during the ten months it has been in use. The deposit is greatest in the lower tubes of the boiler, and decreases in the upper rows: practically it is prevented from accumulating so thick as to cause the tubes to be injured by the heat, since it becomes cracked and loosened from the tubes by their alternate expansion and contraction under the varying temperature of the fire.

At times also nearly all the water is worked out of the tubes so as to let them get quite hot, but not hot enough to cause injury by overheating; and when the deposit is thus loosened in the tubes it is washed out into the receiver by the circulation of the water. The dirt and scale are cleared out of the receiver by a blow-off cock, which is opened for blowing off two or three times a day. It takes about a quarter of a minute to free the blow-off cock from the deposit lodged in the receiver before a full body of water issues from it. Pieces of deposit are blown off which have a circular form, showing that they have been formed in the tubes and then scaled off and washed into the receiver. The semicircular form of the bends uniting the ends of the tubes prevents any incrustation lodging in them by giving an unobstructed passage.

The mode of uniting the tubes together in the former boilers of this construction was with right and left handed screws cut on the ends of the tubes and screwed into the bends: but this make required an entire section of the boiler to be taken out when a new tube had to be put in; and with large boilers this is too much trouble, owing to weight, difficulty of handling, and the impossibility of unscrewing many of the tubes in the bends after they have once been screwed up and put to work. To meet these difficulties a new form of bend has been made in the present boiler, which admits of any one of the tubes in any part of the boiler being taken out, without removing that section of the boiler or interfering with any other joints than those of the tube to be removed. Figs. 4, 5, 8, and 9, Plate 8, show enlarged views of the improved bends. Instead of screwing the ends of the tubes they are made with collars of suitable size welded on, and the ends of the bends are recessed out to receive them: the bends are brought up tight against the collars on the tubes by the centre screw bolt M, Fig. 8, which passes through a hole in the bend in line with the centres of the two tubes, and is screwed into the crossbar N bearing against the outside face of the collars. The passage through the bend is made on one side of the fixing bolt, Fig. 9, to prevent it from obstructing the flow of steam and water. By this plan any of the bends can be taken off through the doorways at the front and back

of the boiler, and any tube can be taken out and replaced. The ends of the tubes are passed through the end bearing plates PP, Figs. 4 and 5, which serve also as shield plates to protect the cast iron bends from the heat of the fire; these plates rest on the walls of the furnace, or are suspended at the top from the girders Q, as in Fig. 2. Figs. 6 and 7, Plate 8, show the mode of joining the tubes to the main supply and delivery pipes, which is done in a similar manner by collars upon the ends of the tubes fitting into recesses in the main pipes and held up tight by a crossbar N and stud bolt. By having valves for cutting off the communication between the receiver and tubes, the steam and water can be retained in the receiver during the time of removing a tube; and when distilled water from a surface condenser is used in the boiler, the water can by this means be saved if a tube should burst, and shut off from the boiler while the repairs are done.

The special advantage of this boiler is that steam of high pressure is generated in it with greater safety than steam of low pressure in ordinary boilers. Its construction ensures almost perfect safety: for the receiver C, Fig. 1, Plate 7, the only portion containing any quantity of steam and water capable of causing damage by explosion, is of the strongest form for resisting pressure, of simple construction, and removed from the action of the fire, so that it is entirely free from the injurious effects of overheating and the alterations of expansion and contraction, which are considered to be the cause of so many injuries and explosions of ordinary boilers. The only portion of the boiler exposed to the fire is the tubes, which are of such small capacity that their explosion is incapable of doing any damage and can only cause the fire to be put out by the water escaping from them. This has been confirmed by the experience with the boiler at the writer's works, where a tube has burst on more than one occasion, whilst the boiler and engine were at work; and the effect was so small that the accident was not immediately perceived, until shown by the loss of steam pressure, the steam and water blowing out upon the fire through the leak in the split tube and putting it out. The advantages of high pressure steam are now generally recognised; but a much higher pressure than can be obtained in ordinary boilers and superheating of the steam are required to develop these advantages fully, by cutting off

the steam earlier with a higher degree of expansion. The economy of expansion is now limited by the weakness of boilers in general use; and a large increase of economy may be obtained if much higher pressures can be safely used.

The leading feature of this boiler is the use of the circulating pump, to maintain a constant and regular circulation of the water through the entire set of tubes forming the heating surface of the boiler. This principle of mechanical circulation is found essential in order to carry out completely the idea of a tubular boiler, in which the heating surface consists entirely of the tubes having the pressure internal, and thereby attaining a maximum of strength and safety with a minimum of material. The rapid generation of steam in the lower portion of such a boiler would so far choke the passage of the tubes as to check the natural circulation of the water and cause the tubes to be rapidly burnt out. The objection arising at first against the adoption of artificial or forced circulation instead of natural,—that it is not self-acting and may therefore be liable to cause interruption to the working of the boiler,—has been satisfactorily proved by the results of the continued working of this boiler to be practically met by the simplicity of construction of the circulating pump, as shown in Fig. 10, Plate 9, previously described. During the ten months that the boiler has been in continual work the circulating pump has always worked well, and never given any trouble except from causes foreign to its principle of working; such as the water freezing in it and breaking it, which occurred once during the late severe frost. In first raising steam in the boiler no difficulty is experienced from the circulating pump not being at work, since the tubes do not require circulation of the water until steam is raised, and the pump then starts with a small pressure of steam, so little power being required to work it.

The portability of this boiler is an important practical advantage for several cases of application. The largest piece, the receiver, is only one tenth the size of an ordinary boiler of the same power; and the tubes can be packed in bundles, giving great advantage for shipping over other boilers both in the reduction of total weight and in the

increased facility for stowage. The economy of space is very great, and an important advantage in many situations where space is limited and valuable; the space occupied being only one sixth to one fourth of that required for ordinary Cornish or cylindrical boilers of the same power.

Owing to the duplication of parts in its construction, the cost of the boiler is but little more than that of ordinary boilers above 25 horse power, including the circulating pump and all the mountings. A small boiler of the kind costs more in proportion than a large one; for in all cases it is best to have an independent circulating pump, and a small pump costs nearly as much as a large one. In this comparison it is supposed that the steam is worked at the ordinary pressures in both cases, say from 25 to 50 lbs. per square inch; but the suitable working pressure for the new boiler is 100 to 150 lbs. per square inch, with the steam superheated and worked expansively; when thus worked and compared with other boilers in first cost per horse power, the new boiler is much cheaper, and in all cases far cheaper for transporting and setting in masonry. The average thickness of the boiler tubes is not more than $\frac{1}{8}$ inch, and their whole surface is effective heating surface; this results in a great saving of weight compared with ordinary boilers with plates $\frac{3}{8}$ to $\frac{1}{2}$ inch thick. In comparison with marine boilers the new boiler can be made much cheaper than those on the ordinary mode of construction, while the facility for repair gives a decided advantage.

Though the steam and water from the tubes are discharged together into the receiver, there is a complete separation of them, and there has not been the least trouble from priming. More fully to prove the fact of their separation, cocks have been placed on the upper and lower sides of the delivery pipe G, Fig. 1, Plate 7, leading from the tubes to the receiver: from the upper cock nothing but steam was found to issue, and from the lower nothing but water; and supposing priming to be caused by taking steam from boilers exposed to the direct action of the fire, it is effectually prevented in this boiler for the reason that no fire acts upon the receiver containing the water, from which the steam is taken off, and consequently the water remains in a quiet state.

Superheating of the steam is effected by returning the steam from the receiver back by the pipe R, Fig. 2, to the upper part of the furnace and passing it through a sufficient number of superheating tubes S, whence it is taken off by the steam pipe T to the engine. The superheating tubes S are arranged and united together in the same manner as the boiler tubes, and are consequently as simple and convenient to get at for erecting and repairing.

The evaporative duty of the boiler with Staffordshire slack has been $5\frac{1}{2}$ lbs. of water per lb. of fuel, without covering the receiver and steam pipes to prevent condensation. Steam has been raised from the time the first shovel of fire was placed in the furnace when cold, without wood or forced draught, to 10 lbs. pressure in 25 minutes, when the steam was sufficient to start the circulating pump; in 10 minutes more there was 35 lbs. pressure of steam, when the engine was started; and in 10 minutes more, being 45 minutes from the time the first shovel of fire was put in the furnace, all the machinery driven by the engine was in operation and there was sufficient steam to produce all the power required. This was with only $\frac{7}{10}$ths of the boiler or 460 square feet of heating surface, $\frac{3}{10}$ths of the boiler being then not at work. The practice at dinner hours and other times when the engine is stopped has been to close the damper, open the firedoors, and cover the fire with ashes and slack, and work the circulating pump as slow as its construction will permit; this entirely prevents generation of steam, and in the meantime saves the tubes from overheating. For starting the engine again, the fire is stirred up and supplied with coals 5 or 10 minutes before steam is wanted, which is ample time to generate a regular and sufficient quantity of steam to commence working all the machinery driven by an engine of 60 horse power. Steam can be regularly maintained in the boiler that has now been in use for ten months, with a variation of from 10 to 15 lbs. pressure when all the work is on the engine with 40 to 55 lbs. steam in the boiler. The pressure cannot be maintained with quite the same regularity in this boiler as in ordinary boilers, on account of the comparatively small amount of steam room; at the same time it is found that a sufficient quantity of steam is made with regularity enough for all practical purposes.

For the purpose of ensuring that the pressure of steam supplied to the engine shall never exceed the intended limit, and of preventing any risk of injury to the engine by over-pressure arising from the comparatively small steam room in the boiler, the regulating valve shown in Fig. 11, Plate 9, has been designed by the writer, and is found to fulfil this object with complete success. It consists of a double-beat valve U, having a piston V below it fixed upon the same spindle and of the same area as the lower valve, and supported by a spiral spring which presses the valves open. The steam from the boiler, passing through both the valve seats, is delivered to the engine by the pipe W; at the same time it acts upon the top of the piston V, compressing the spiral spring below to a greater or less extent according to the pressure of the steam, and thus partially closing the valve and wiredrawing the steam whenever its pressure at entrance approaches the intended limit. The spiral spring is adjusted so as to hold the valve full open until this limit of pressure is nearly reached; but whenever that takes place, the partial closing of the valve checks the supply of steam and prevents the pressure of the steam supplied to the engine from rising above the intended amount. The bottom of the spiral spring is carried by a cylindrical cap X, sliding vertically and supported by the end of the weighted lever Y, which is adjusted to balance the pressure on the piston at the limit of steam pressure. As soon as the intended pressure is exceeded, this lever is depressed immediately, closing the valve entirely and shutting off the supply of steam, thus preventing any increase of pressure in the steam pipe W when the engine is standing, which would otherwise be occasioned by the accumulation of steam gradually passing through the contracted opening of the valve that serves to supply the engine when working. A safety valve Z is added on the top of the casing to make the precaution complete. This regulating valve is in constant work, and maintains the steam supplied to the engine at a uniform pressure. It may also be applied with advantage to low pressure and high pressure engines working in connexion, serving completely to regulate the limit of pressure of the steam supplied to the low pressure engine.

Mr. Russell exhibited specimens of the joints and bends of the boiler tubes, and some of the burst and incrusted tubes that had been taken out of the boiler, as described in the paper. The new boiler had fully answered his expectations since it had been got to work, both in supply of steam and in safety and facility of repairs under any accident that could occur. It occupied only one sixth the space of the two Cornish boilers previously used, and burnt only 3 tons of slack per day against the previous consumption of $5\frac{1}{2}$ tons per day for doing the same work; one engine only was working now, instead of two, and was working up to 60 indicated horse power. The safety of the boiler was a great advantage, and they had had two or three instances of tubes bursting; but no injury was done, and the only effect was that the fire was put out by the steam and water, and the burst tube was replaced by a new one with only two hours' delay.

Mr. J. Fenton observed that the evaporative duty shown by the boiler was low, amounting to only $5\frac{1}{2}$ lbs. of water per lb. of slack.

Mr. Russell said the boiler was at present very unfavourably circumstanced as to evaporative duty, owing to the steam pipes and receiver not being protected in any way; and much heat from the fire was also lost by passing away into the chimney. The advantage to be obtained by the new boiler in economy of fuel would be fully shown when steam of very high pressure was used, which could be safely done only with a boiler upon that construction.

Mr. G. A. Everitt thought that the consumption of 18 tons of slack per week for an engine of 60 indicated horse power was certainly far from economical; for with Cornish boilers he was burning at his works only 16 tons of slack altogether per week for two engines of 60 nominal horse power, working up to 170 indicated horse power.

Mr. W. Richardson mentioned that in Green's economiser, which he had used for several years past for heating the feed water by the waste heat passing to the chimney, consisting of a stack of upright pipes placed in the chimney flue, through which the feed water was passed on its way to the boiler, cast iron pipes were first used, but they had tried substituting wrought iron pipes, to obtain a thinner

metal that would conduct the heat better; these however all became riddled through with small holes in 18 months, by the destructive action of the condensed water, and had all to be taken out again and replaced by cast iron pipes. The same result had been experienced at several other places where wrought iron pipes had been tried in the economiser; and he feared therefore the wrought iron tubes in the boiler would be destroyed in the same way by their direct exposure to the fire.

Mr. Russell said there had been such long experience of the use of wrought iron tubes in boilers that there was no fear for their durability, and they had been found to last for many years' working with regular circulation through them.

Mr. W. Richardson enquired what degree of superheating was obtained by the superheating tubes in the boiler; he thought this could not be great, as they were placed in the coolest part of the furnace, furthest from the fire. He had tried superheating the steam by tubes placed in the flue beyond the boiler, but found that steam of 70 or 80 lbs. pressure could not be superheated by that arrangement, since the temperature in the flue was scarcely higher than that of the steam itself.

Mr. Russell replied that at 60 or 70 lbs. pressure the steam was superheated about 220° or 240° by passing through the superheating tubes; and after taking out three sections of the boiler tubes the steam was superheated more than 500°, having a temperature of more than 900° after passing through the superheating tubes, in consequence of their having in that case a greater extent of surface exposed direct to the fire, while less of the heat was taken up by the boiler tubes.

Mr. C. W. Siemens observed that the amount of superheating which had been mentioned would go far to explain the low evaporative duty of the boiler; for if the steam were superheated to upwards of 900° by the superheating tubes in their present position close to the chimney, the heat passing away into the chimney must be more than 1000°, which would produce a great loss of fuel. The tubular construction of boiler, in which the entire heating surface consisted of small tubes having great strength to resist internal pressure, was

he thought one that might be advantageously employed, and it had been tried in this country by Dr. Alban many years ago, with steam of 150 to 200 lbs. pressure. In the present boiler the circulating pump was the novel feature, producing an artificial circulation of the water through the tubes; but he questioned the desirability of introducing such a system, on account of the additional complication involved, and thought the plan might be simplified by some alteration in the arrangement, so as to rely on natural circulation alone.

Mr. A. Masselin remarked that the superheating tubes at the top of the boiler next to the chimney were in the least effective position for superheating the steam; and would have been placed with much greater advantage at the bottom of the boiler, immediately over the furnace, if sufficiently durable to stand so close to the fire.

Mr. Benson said the special feature of the boiler was the forced circulation of the water, to prevent the tubes ever being short of water; he was satisfied that a boiler of this construction would not last more than five or six months, were it not for the mechanical circulation, for the tubes would soon tear themselves to pieces by unequal expansion and contraction if exposed to the risk of being alternately full and empty of water, which they would be liable to if dependent on natural circulation. In the case of water heaters that had been referred to, the tubes were soon eaten through by corrosion, and became forced out of position and twisted round, owing to the small quantity of water passing through them; but no such results had been experienced in the tubes of the boilers, because the quantity of water passed through them by the forced circulation was so much greater than that evaporated. The bottom tubes were made $1\frac{1}{4}$ inch diameter for one third the height of the boiler, then $1\frac{1}{2}$ inch for the next third, and $1\frac{3}{4}$ inch at the top, which gave an additional security for the bottom tubes being always thoroughly filled with water, while greater freedom of passage was allowed at the top for the mixed water and steam escaping into the receiver.

The chief improvement made since the erection of the first boiler on this construction was the mode of fixing the tubes, in such a manner as to allow of removing and replacing any tube without taking out an entire section of the boiler; a tube could now be taken

out and a new one put in in as short a time as 15 to 20 minutes, when the boiler was again ready for work at once.

When the boiler was properly constructed, he had found the evaporative duty was equal to that of any tubular boiler; but in the present instance the boiler was not working under favourable circumstances for economy of fuel. The sections of the boiler were set $1\frac{1}{2}$ inch apart, and much heat escaped between them direct into the chimney. The draught was also deficient, the chimney being only 2 feet diameter which was too small for the purpose; so that there was not air enough drawn in for thorough combustion of the coal, and smoke generally issued from the chimney for a short time after firing.

The Chairman asked whether there were any openings for admitting air over the surface of the fire to prevent the smoke.

Mr. Benson replied that a number of air holes were made in the brickwork on all sides of the furnace, but these were not sufficient to prevent smoke without a greater force of draught.

The Chairman moved a vote of thanks to Mr. Russell for the paper, which was passed.

The following paper was then read :—

DESCRIPTION OF A METHOD OF SUPPLYING WATER TO LOCOMOTIVE TENDERS WHILST RUNNING.

By Mr. JOHN RAMSBOTTOM, of Crewe.

The object of the apparatus forming the subject of the present paper is to supply Locomotive Tenders with Water without requiring the stoppage of the train for the purpose. It consists of an open trough of water, lying longitudinally between the rails at about the rail level; and a dip-pipe or scoop attached to the bottom of the tender, with its lower end curved forwards and dipping into the water of the trough, so as to scoop up the water and deliver it into the tender tank whilst running along.

The construction of the apparatus is shown in Figs. 1 and 2, Plate 10, which are longitudinal and transverse sections of the tender and water trough. Figs. 3 and 4, Plate 11, are longitudinal and transverse sections enlarged of the scoop and trough.

The water trough A of cast iron, 18 inches wide at top by 6 inches deep, Fig. 4, Plate 11, is laid upon the sleepers between the rails at such a level that when full of water the surface of the water is 2 inches above the level of the rails, as seen in Figs. 1 and 2, Plate 10. The scoop B, for raising the water from the trough, is of brass, with an orifice 10 inches wide by 2 inches high, as shown in Figs. 3 and 4; when lowered for dipping into the trough, its bottom edge is just level with the rails and immersed 2 inches in the water. The water entering the scoop B is forced up the delivery pipe C, Fig. 1, which discharges it into the tender tank, being turned over at the top so as to prevent the water from splashing over. The scoop is carried on a transverse centre bearing D, and when not in use is tilted up by the balance weight E clear of the ground, as shown dotted in Fig. 3; for dipping into the water trough it is depressed by means of the handle F from the footplate, which requires to be held by the engineman as long as the scoop has to be kept down.

The upper end of the scoop B is shaped to the form of a circular arc, Fig. 3, as is also the bottom of the delivery pipe C, so that the scoop forms a continuous prolongation to the pipe when in the position for raising water. The limit to which the scoop is depressed by the handle F is adjusted accurately by the set screws G, which act as a stop and prevent the bottom edge of the scoop being depressed below the fixed working level; the set screws also afford the means of adjusting the scoop to the same level when the brasses and tyres of the tender have become reduced by wear, causing the level of the tender itself to be lowered. The orifice of the scoop is made with its edges bevilled off sharp, to diminish the splashing, and the top edge is carried forward 2 or 3 inches and turned up with the same object.

Two other forms of scoop have been used, but they are not considered so eligible as that already described and shown in Figs. 3 and 4, Plate 11. In one of them the scoop was hinged on the bottom of the delivery pipe C along the front edge, with a set screw as before for adjusting it to the proper level in the trough when the brasses and tyres have become worn. The other form of scoop was made to slide up inside the delivery pipe with a telescope joint; and for adjusting its height the lifting lever was centered in an eccentric bush which could be turned round when necessary, so as to raise the lever and allow for the wear of the brasses and tyres.

The water trough A is cast in lengths of about 6 feet, so as to rest upon each alternate sleeper, and is fixed to the sleepers, the height being adjusted by means of the wood packing, as shown in Figs. 1 and 2, Plate 10. The ends of each length are formed with a shallow groove, in which is inserted a strip of round vulcanised india-rubber H, Fig. 3, to make a flexible and water-tight joint, the metal not being in contact; this meets all the disturbances arising from expansion, settlement of road, and vibration caused by the passage of trains. The length of trough now laid on the Chester and Holyhead Railway near Conway is 441 yards in the level, as shown in the diagram Fig. 5, Plate 12; and at each end the rails are laid at a gradient of 1 in 100 for a further length of 16 yards,

the road being raised for that purpose so that the summit of the incline is 6 inches higher than the level portion: the trough is tapered off in depth to a bare plate, so that the same thickness of wood packing serves for fixing it throughout the entire length. The portion of the line where the trough is fixed is a curve of 1 mile radius, and the outer rail is canted 1 inch above the inner, the wood packing being made taper for fixing the trough horizontal; but the cant does not interfere with the efficient action of the scoop on the tender, since it amounts to only 1–6th inch on the 10 inches width of scoop. At each extremity of the water trough is an overflow pipe I, Fig. 5, limiting the height of water in the trough.

Where the water has to be raised by pumping or the natural supply is limited in amount, it is necessary to prevent the water running to waste through the overflow pipes. For this purpose the supply pipe K, Fig. 6, Plate 12, has a valve L fitted on its orifice, and delivers the water into the small cistern M, from which it flows into the trough A through the pipe N; when the trough is full up to the high water level, the water overflows from the cistern into the pocket O and thence into the bucket P on the end of the valve lever, closing the valve and cutting off the supply water. There is a small hole in the bottom of the bucket P, through which the water in the bucket constantly escapes: so that when the water level in the trough A has been lowered by the passage of an engine, the water in the cistern M no longer overflows into the bucket P, and that in the bucket escapes through the hole at the bottom, allowing the valve lever to be raised by the balance weight at the other end and open the valve for a fresh supply. By this means a large quantity of water is economised, since there is only the small quantity escaping through the hole in the bucket, instead of the water constantly running to waste through the large overflow orifices at the two extremities of the trough.

The trough contains 5 inches depth of water, and the scoop dips 2 inches into the water, leaving a clearance of 3 inches at the bottom of the trough for any deposit of ashes or stones. The trough is so constructed as to present no obstruction to be caught by any loose couplings or drag chains that may be hanging from the trains

passing over it; and experiments have been tried with a bunch of hook chains and screw couplings hanging down behind the tender and dragged along the trough without any damage occurring.

As to any difficulty from ice, a thorough trial has been afforded by the late severe weather. By means of the small ice plough shown in Figs. 7, 8, and 9, Plate 12, which was run through the trough by hand each morning, the coating of ice was removed from the surface of the water, and no more was formed afterwards excepting a film so thin that it was removed by the scoop itself in passing through the trough without being felt at all. It has indeed been shown that the continuance of this action with the succession of trains in ordinary working would be sufficient in this climate to prevent the formation of any ice thicker than could be readily and safely removed by the passage of the scoop alone, even during as severe a season as the last. The present trough, which has been in use nearly three months, is supplied hitherto by a pump, which it may be here mentioned failed once through being frozen up; but a natural stream of water will shortly be connected to it, giving a regular supply by gravitation, and serving to prevent the water freezing by maintaining a constant current through the trough.

The principle of action of this apparatus consists in taking advantage of the height to which water rises in a tube, when a given velocity is imparted to it on entering the bottom of the tube: the converse operation being carried out in this case, the water being stationary and the tube moving through it at the given velocity.

The theoretical height, without allowing for friction &c., is that from which a heavy body has to fall in order to acquire the same velocity as that with which the water enters the tube. Hence, since a velocity of 32 feet per second is acquired by falling through 16 feet, a velocity of 32 feet per second or 22 miles per hour would raise the water 16 feet: and other velocities being proportionate to the square root of the height, a velocity of 30 miles per hour would raise the water 30 feet very nearly (a convenient number for reference), and 15 miles per hour would raise the water $7\frac{1}{2}$ feet; half the velocity giving one quarter the height. In the present apparatus

the height that the water is lifted is $7\frac{1}{2}$ feet from the level in the trough to the top of the delivery pipe in the tender, which requires theoretically a velocity of 15 miles per hour; and this is confirmed by the results of experiments with the apparatus: for at a speed of 15 miles per hour the water is picked up from the trough by the scoop and raised to the top of the delivery pipe, and is maintained at that height whilst running through the trough, without being discharged into the tender.

The theoretical maximum quantity of water that the apparatus is capable of lifting is the cubic content of the channel scooped out of the water by the mouth of the scoop in passing through the entire length of the trough: this measures 10 inches width by 2 inches depth below the surface of the water in the trough, and 441 yards length, amounting to 1148 gallons or 5 tons of water. The maximum result in raising water with the apparatus is found to be at a speed of about 35 miles per hour, when the quantity raised amounts to as much as the above theoretical total: so that in order to allow for the percentage of loss that must unavoidably take place, it is requisite to measure the effective area of the scoop at nearly the outside of the metal, which is $\frac{1}{4}$ inch thick and feather-edged outwards, making the orifice slightly bell-mouthed and measuring at the outside $10\frac{1}{2}$ inches by $2\frac{1}{4}$ inches; this gives 1356 gallons for the extreme theoretical quantity.

The result of a series of experiments at different speeds is that

(22 Jan. 1861)	at 15 miles per hour the total delivery is	0	gallons.
„	22	1060	„
„	33	1080	„
„	41	1150	„
(23 Nov. 1860)	50	1070	„

Hence it appears that the variation in the quantity of water delivered is very slight at any speed above 22 miles per hour, at which nearly the full delivery is obtained; the greater velocity with which the water enters at the higher speeds being counterbalanced by the reduction in the total time of action whilst the scoop is traversing the fixed length of the trough. It also appears that at any speed above that which is sufficient to discharge the water freely from the top of the delivery pipe, all the water displaced by the scoop is

practically picked up and delivered into the tender. In these experiments the water level was maintained the same in the trough each time by keeping it supplied up to the overflow orifice at each end; and the scoop was lowered to the same level each time by means of the set screws, the height of the tender itself being maintained practically the same in each case.

At higher speeds than 22 miles per hour the velocity of the water entering the scoop is much greater than is required to raise it to the height of the tender; and on taking up the water by a prolonged vertical pipe curved forwards at the bottom end, in place of the scoop, it is thrown upwards in a strong jet. By closing the top of this pipe and connecting it to a pressure gauge, it has been found that at a speed of 50 miles per hour the water exerted a pressure in the pipe of 30 lbs. per square inch, maintaining the gauge at this pressure during the passage through the trough. This pressure is equivalent to a column of water 70 feet high, and the velocity due to that height is 46 miles per hour, confirming the actual speed of 50 miles per hour. In order to diminish the velocity at which the water enters the tender tank, the delivery pipe is enlarged continuously from the bottom to the upper end, making the area for discharge 10 times that for entrance, as shown in Fig. 2, Plate 10, so that at 50 miles per hour the water is discharged into the tender at only 5 miles per hour or 7 feet per second, equivalent to falling a height of about 1 foot. The theoretical form for the taper of this pipe for giving a uniform degree of retardation to the current of water throughout its length would be a parabolic curvature hollowed inwards at the sides; but the form considered most eligible in practice is one of uniform taper, to allow more freedom of passage in the middle of its length. The form of the front or convex side of the pipe is however of little moment, as the stream of water flows up the back or concave side without pressing against the convex side, which might indeed be removed in the lower portion of the length, leaving the pipe an open curved trough, without risk of the water escaping.

In the preliminary experiments before constructing the apparatus, a trial was made of the effect of a stream of water issuing through an open trough attached to the end of a large water main, under such a

pressure that a regular stream of water was maintained at a speed of 15 miles per hour. A curved pipe similar in form to the scoop and delivery pipe in the drawings and about 3 feet high was placed in the stream of water facing the current, and the water was found to be raised up the pipe and freely discharged in a stream from the top: the orifice of the pipe was 2 inches by $\frac{1}{4}$ inch at the bottom and 2 inches by 2 inches at the top, being an increase in area of 8 times. On placing a $\frac{3}{8}$ inch pipe bent at the bottom to face the current, the water did not cease to flow over till the top was raised $7\frac{1}{2}$ feet above the level of the stream.

For the purpose of measuring the speed conveniently during some of the experiments, the writer employed the simple instrument shown in Figs. 10 to 13, Plate 13, consisting of a small vertical glass cylinder R half full of oil, made to rotate rapidly on its axis by a cord passed round the trailing axle S of the engine: the depressed centre of the surface of the rotating oil indicated readily and accurately the speed of running by the graduated scale at the side of the glass cylinder.

The principle of action of this plan of raising water for supplying locomotive tenders occurred to the writer several years ago, and he long felt convinced that it admitted of being made practically available for that purpose with some advantages of importance in removing difficulties that are at present experienced under certain circumstances of working the traffic. His attention was forcibly called to this on occasion of having to provide last year for the accelerated working of the Irish mail, which has now to be run through from Chester to Holyhead, a distance of $84\frac{3}{4}$ miles, without stopping, in 2 hours and 5 minutes. This necessitated an increase in the size of the tender tanks beyond the largest size previously used containing 2000 gallons; or else required the alternative of taking water half way at Conway, either by stopping the train for the purpose, or by picking up the water whilst running. A supply of 2400 gallons is found requisite for this journey in rough weather; and although 1800 to 1900 gallons only are consumed in fair weather, it is necessary to be always provided for the larger supply, on account

of the very exposed position of the greater portion of the line, which causes the train to be liable to great increase of resistance from the high winds frequently encountered. An increase of the tender tanks beyond the present size of 2000 gallons would have involved an objectionable increase of weight in construction, and alteration in the standard sizes of wheels and axles &c. for tenders; and would have also caused a waste of locomotive power in dragging the extra load along the line. By this plan of picking up 1000 gallons of water at the half way point near Conway, where the water trough is fixed, the necessity for a tender larger than the previous size of 1500 gallons is avoided, effecting a reduction in load carried equivalent to another carriage of the train.

Another application contemplated for this apparatus is to the case of heavy through goods trains, such as those between Liverpool and Manchester, which are at present required to stop half way at Parkside for water only, causing an objectionable blocking of a line very much thronged with traffic, and a delay and loss of power in pulling up the heavy train.

Another advantage of this plan is the means it affords of opening up fresh sources of water supply, where a stream of good water can be obtained near the level of the rails without expense and labour of pumping it, but cannot be otherwise made available on account of not being at a station: such as the case of the Holyhead line, where at the terminus on the coast the supply of water is defective in quality and quantity, and involves heavy expense for pumping; but at about 15 miles distance along the line a plentiful natural supply of good water can be obtained at the rail level in the middle of the island of Anglesea, where however the nature of the traffic does not necessitate a stoppage.

Mr. Ramsbottom showed a working model of the apparatus to illustrate the mode of action: and observed that the plan had been matured to meet the special difficulty of working the traffic without any delay for taking in water; it had proved quite successful in practice, and thoroughly accomplished the object intended, and there

was indeed less trouble in taking water with it than with an ordinary water crane. Many plans had been suggested for lowering the scoop into the trough, but none so simple and complete as that adopted of making the line with an incline at each end of the trough; the bottom of the scoop when lowered was level with the rails and quite clear of the ballast, so that it might be lowered a mile before reaching the trough; and it was then gradually dipped down into the water and lifted out again by the incline in the rails at each end, passing 3 inches clear above the ends of the trough. In practice instead of the whole quarter of a mile length of line being lowered 6 inches, only a short double incline was made at each end, rising 6 inches and then falling the same amount towards the end of the trough, the object being to enable the scoop to clear the end of the trough. The velocimeter exhibited was a simple instrument that he had contrived for some previous experiments; it showed the speed correctly by simple inspection, assisting the driver in maintaining a uniform speed in experiments, and was convenient for connexion to the engine.

Mr. C. Markham had had an opportunity of examining the working of the apparatus described in the paper, and could confirm the statements that had been made as to its efficiency. On running an engine through the trough at a speed of about 45 miles per hour, it was ascertained by measurement that more than 1100 gallons of water had been delivered into the tender; and in another experiment the speed of the engine was got up gradually from a state of rest to about 16 miles per hour, at which speed the water began to flow over into the tender freely. He had examined the trough and found it in perfect order, the joints being tight without any leakage. This mode of supplying tenders with water would be of great advantage for long runs, especially where a great speed was required, as it avoided the delay of stopping for water; it would also prove of considerable advantage in the working of through goods trains, by preventing the loss of power in pulling up a heavy train for water only. He doubted however whether there were many railways in this country that would admit of the plan being generally adopted, because it was necessary at each place to have a level of a quarter of a mile long for laying

down the water trough, which could not always be obtained. Where there was a good natural supply of water, the plan appeared a valuable auxiliary means of supplying the tender with water; but he thought it should be regarded as auxiliary, for the engine might be stopped before reaching the trough, at too short a distance to allow of getting up the necessary speed for raising the water, causing detention unless the troughs were numerous along the line.

Mr. Ramsbottom remarked that for picking up water at very low speeds he had proposed placing a flap valve at the bottom of the tender, opening inwards, instead of carrying the delivery pipe up to the top of the tender and turning it over; by this means some height would be saved. At as low a speed however as 22 miles per hour the water was supplied in full quantity to the height of 7½ feet.

Mr. J. E. Clift enquired what amount of power was expended in raising the water into the tender whilst running.

Mr. Ramsbottom said the power expended would be little more than the weight of the water lifted to the height through which it was raised, with some addition for friction in the scoop and delivery pipe; there was indeed in this plan a saving of power due to the water having to be raised only to the height of the tender, instead of into a high tank for supplying the water cranes.

The Secretary confirmed the statements given in the paper as to the results of working, having been present at the experiments and witnessed the action of the apparatus in work; and the water trough was found to be in complete order after exposure to the long severe frost.

The Chairman thought the results of the trials were highly satisfactory and showed the success with which the plan had been carried out. He proposed a vote of thanks to Mr. Ramsbottom for his paper, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Fourteenth Anniversary of the Institution.

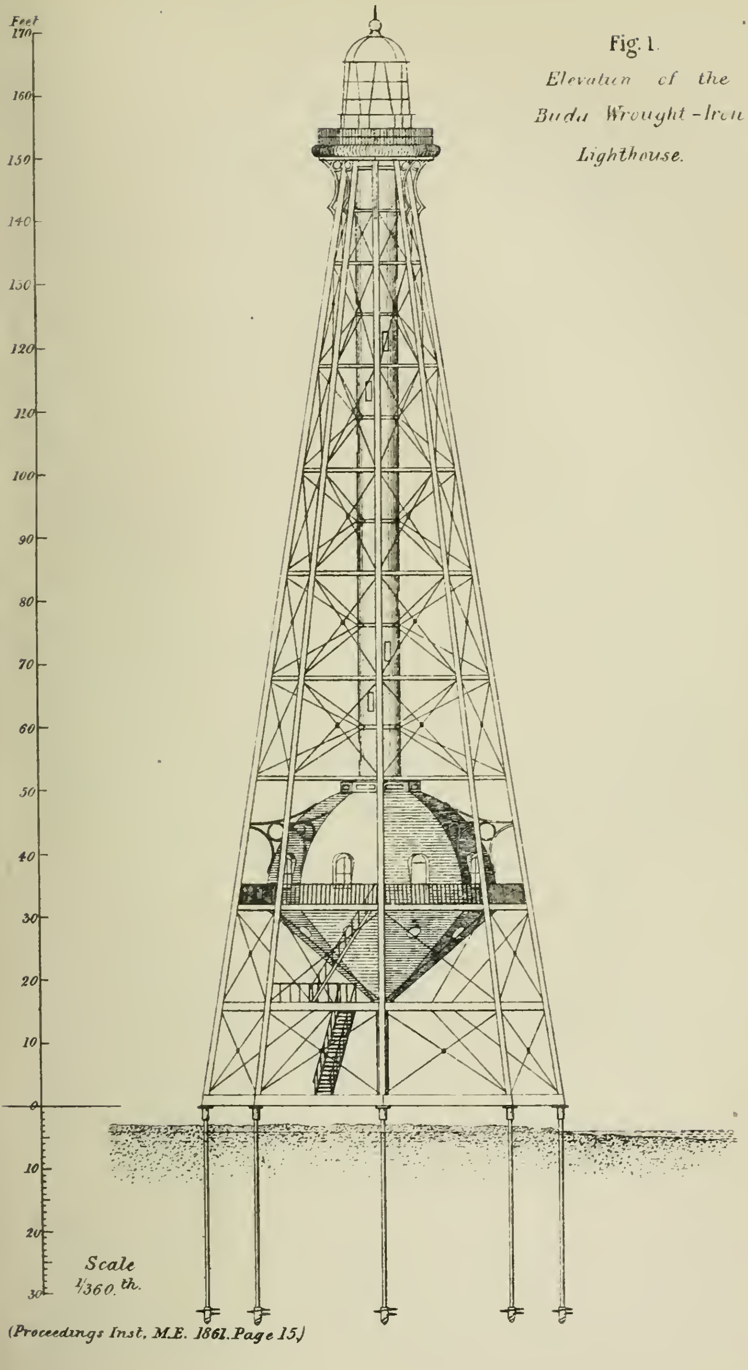


Fig. 1.
Elevation of the Buda Wrought-Iron Lighthouse.

(Proceedings Inst. M.E. 1861. Page 15.)

Fig. 2. *Map of mouths of Ebro showing position of Lighthouses.*

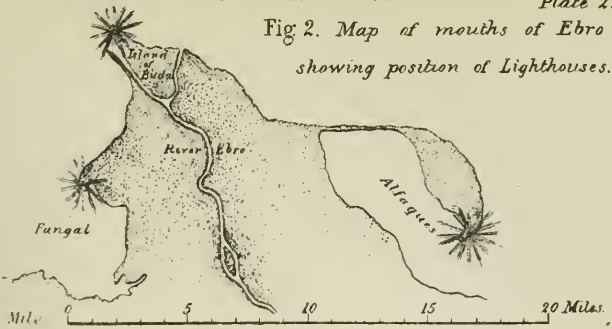


Fig. 3. *Diagram Plan at Base.*

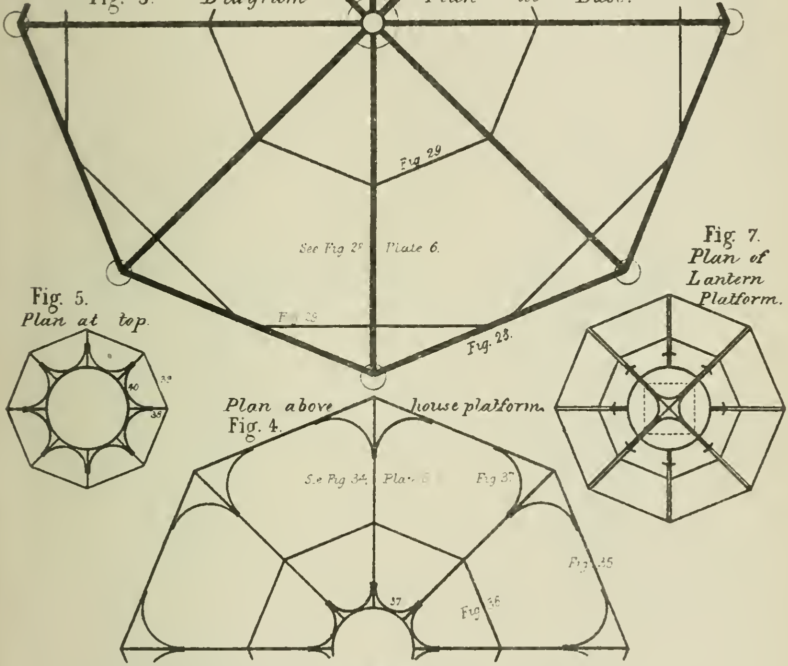
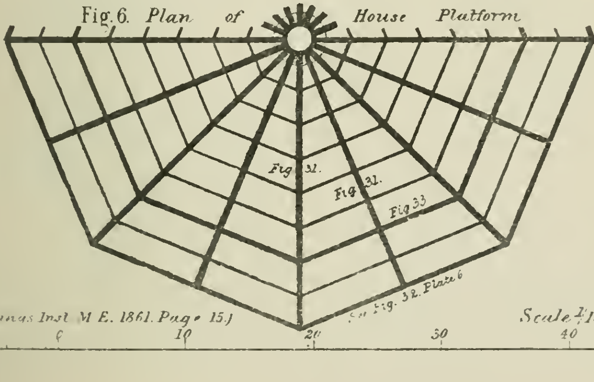


Fig. 6. *Plan of House Platform.*



(Proceedings Inst. M. E. 1861. Page 15.)

Scale 1/180th.

10 5 0 10 20 30 40 50 Feet.

Fixing of main Pillars on Piles.

Fig. 8. *Plan.*

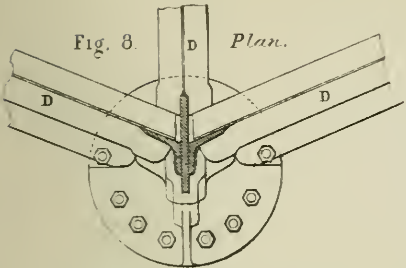


Fig 10. *Plan of Pile Cap.*

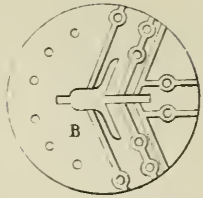


Fig. 9. *Elevation.*

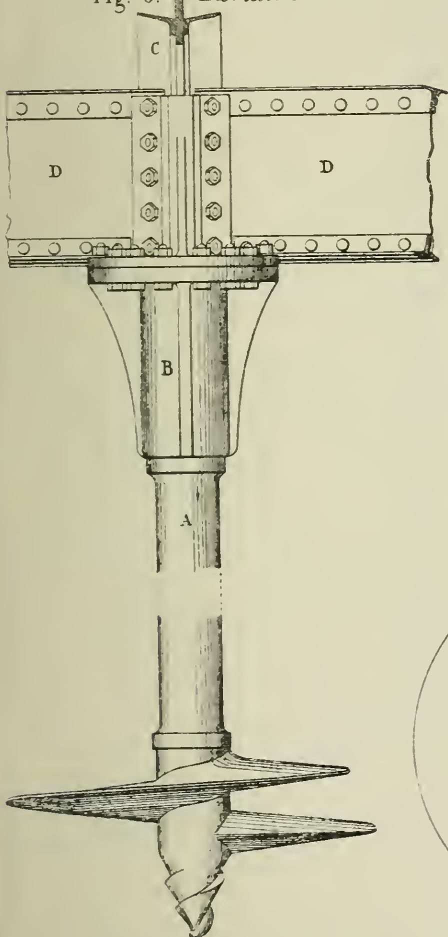
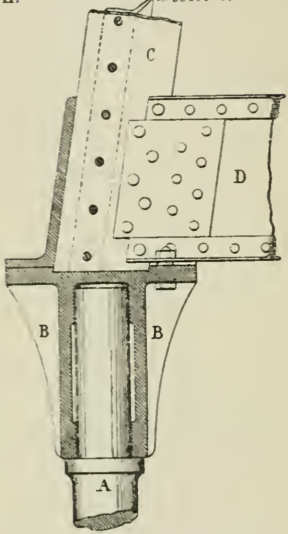
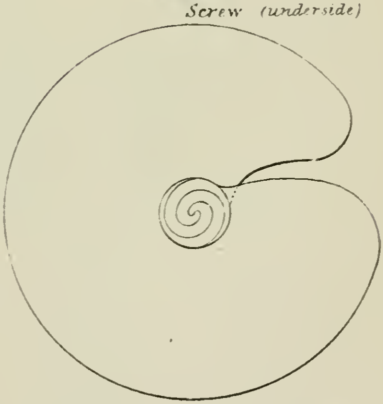


Fig. 11. *Section.*



Screw (underside)



Scale $^{1}/_{24}{}^{th}$ 10 5 0 10 20 30 40 50 *Inches*

(Proceedings Inst. M.E. 1861. Page 15.)

WROUGHT – IRON LIGHTHOUSE.

Plate 4

Cast Iron Centre Column below house platform.

Section at XX.

Fig. 14.

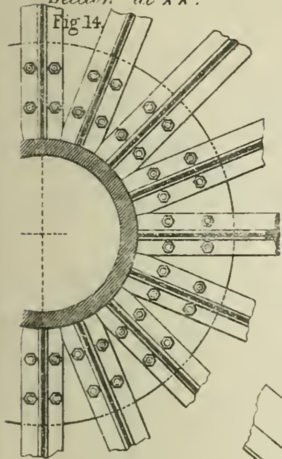
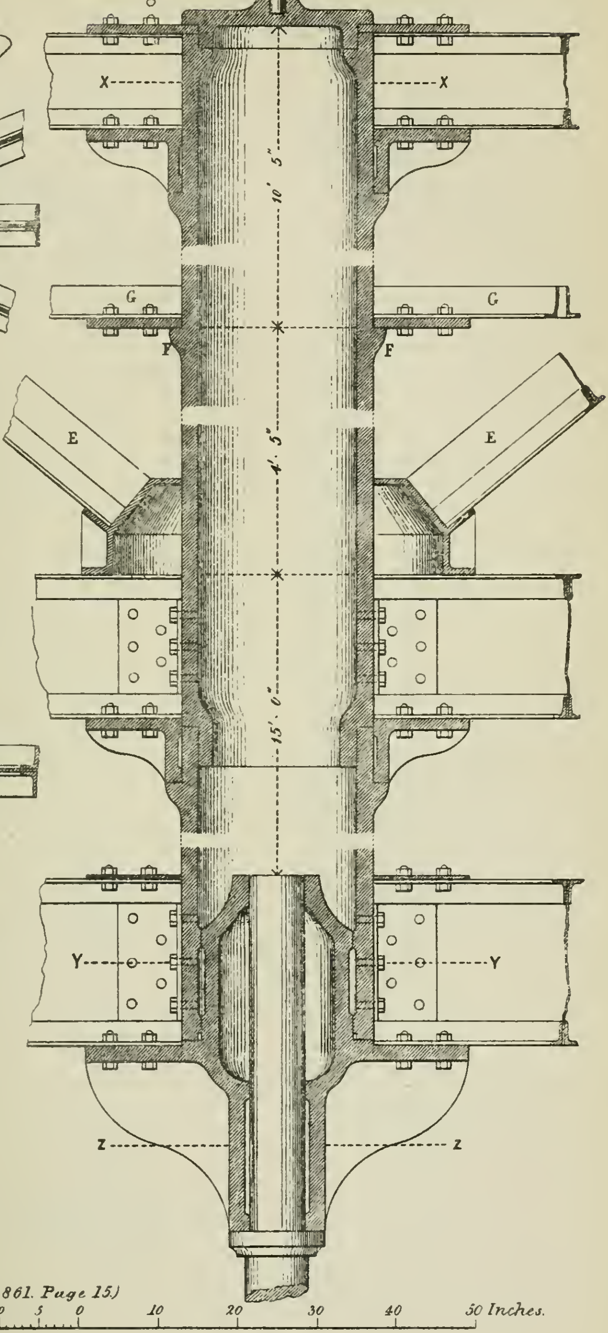
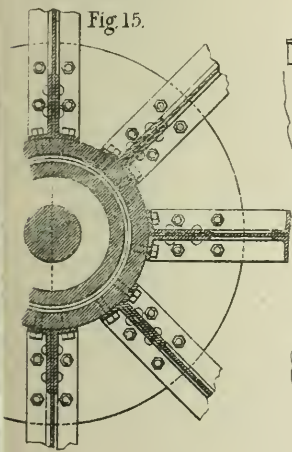


Fig. 13. *Vertical Section.*



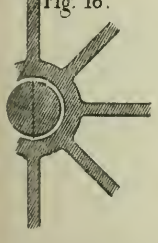
Section at YY.

Fig. 15.



Section at ZZ.

Fig. 16.



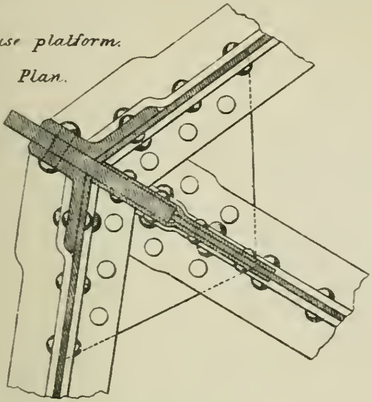
(Proceedings Inst. M.E. 1861. Page 15.)

Scale 1/24th. 10 5 0 10 20 30 40 50 *Inches.*

Attachment of horizontal Girders to Corner Pillars.

Below house platform.

Fig. 17. *Plan.*



Above house platform.

Fig. 19. *Plan.*

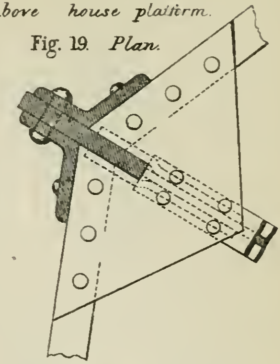


Fig. 18. *Elevation.*

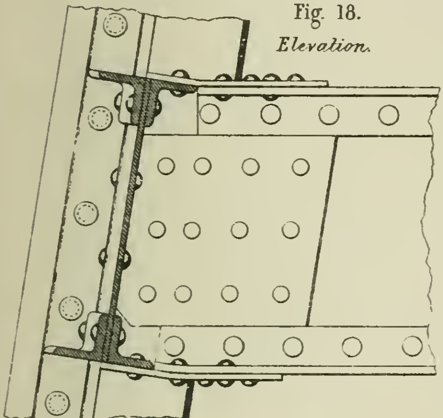
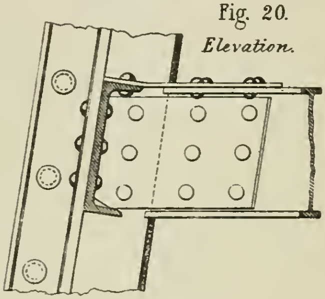


Fig. 20. *Elevation.*



Attachment of horizontal Girders to staircase Tower, (above house platform)

Fig. 21. *Elevation.*

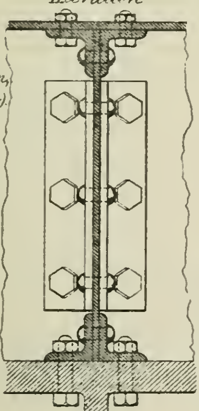
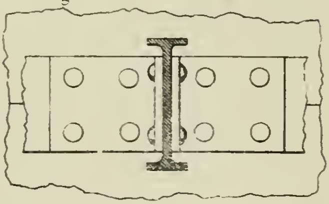


Fig. 23. *Elevation.*



Attachment of horizontal Girders to cast iron Centre Column, (below house platform).

Fig. 22. *Plan.*

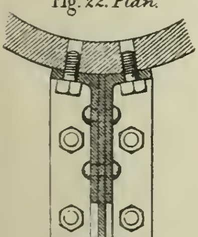
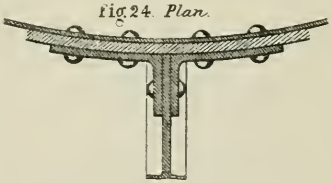


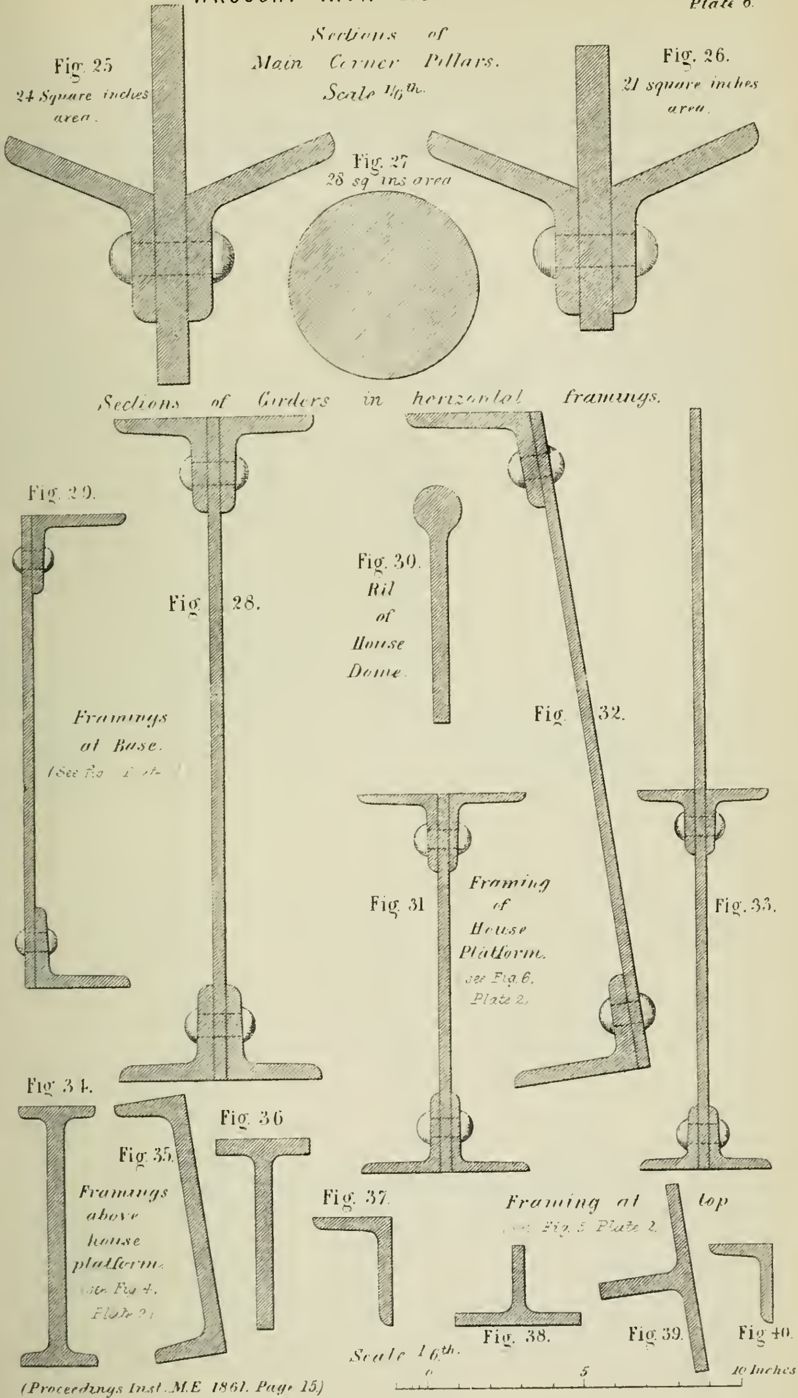
Fig. 24. *Plan.*



Scale 1/12th.

0 5 10 15 20 Inches

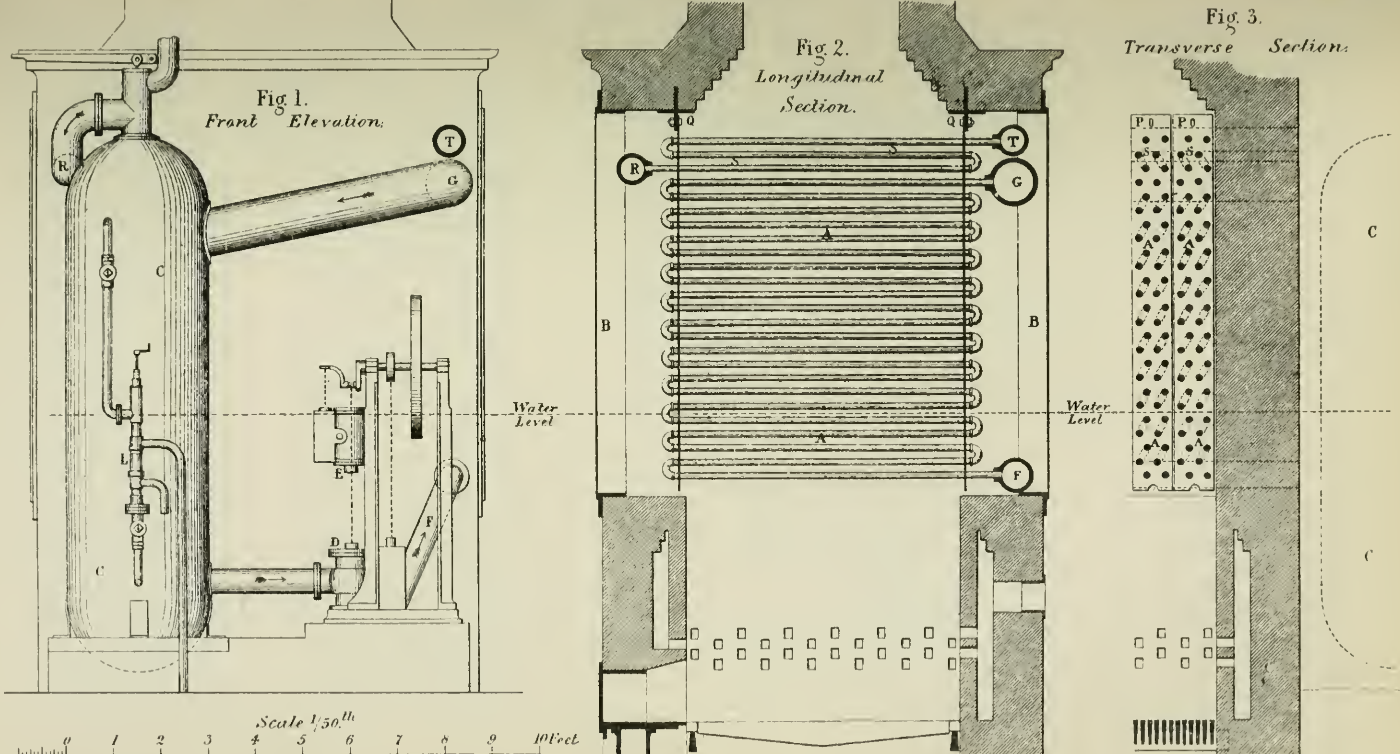
(Proceedings Inst. M.E. 1861. Page 15.)



(Proceedings Inst. M.E 1861. Page 15)

HIGH-PRESSURE STEAM BOILER.

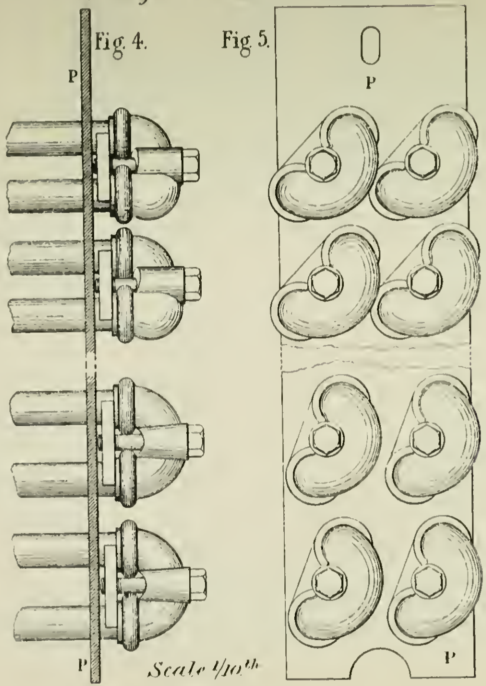
Plate 7.



(Proceedings Inst. M.E. 1861. Page 30.)

Fixing of Tubes in boiler.

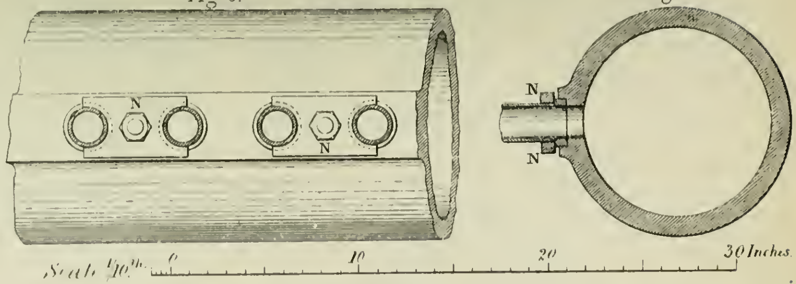
Fig. 4. Fig 5.



Scale 1/10th

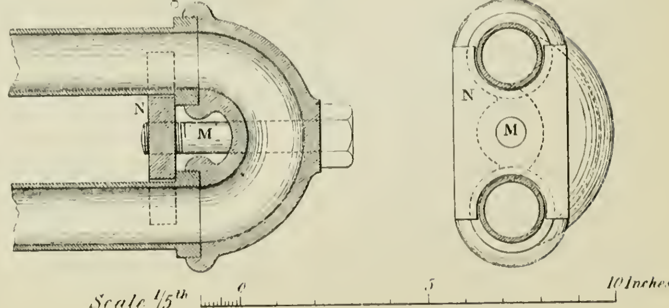
Connexion of Tubes to main supply and delivery pipes.

Fig 6. Fig. 7.



Connexion of Tubes and Bends, enlarged.

Fig. 8. Fig 9.



(Proceedings Inst. M.E. 1861 Page 30.)

HIGH-PRESSURE STEAM BOILER.

Fig. 10.
Circulating Pump.

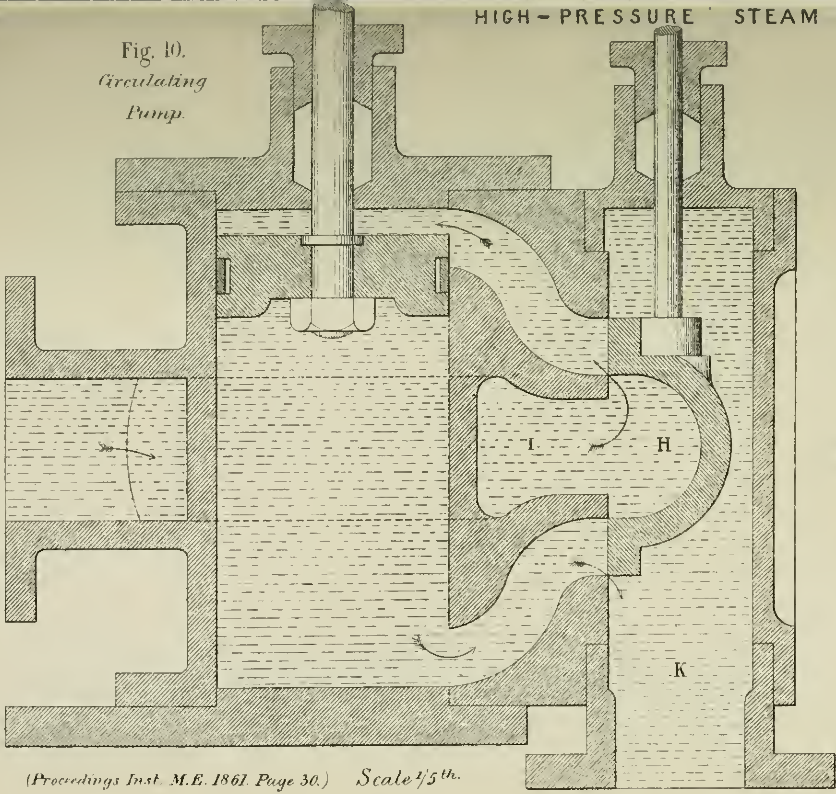
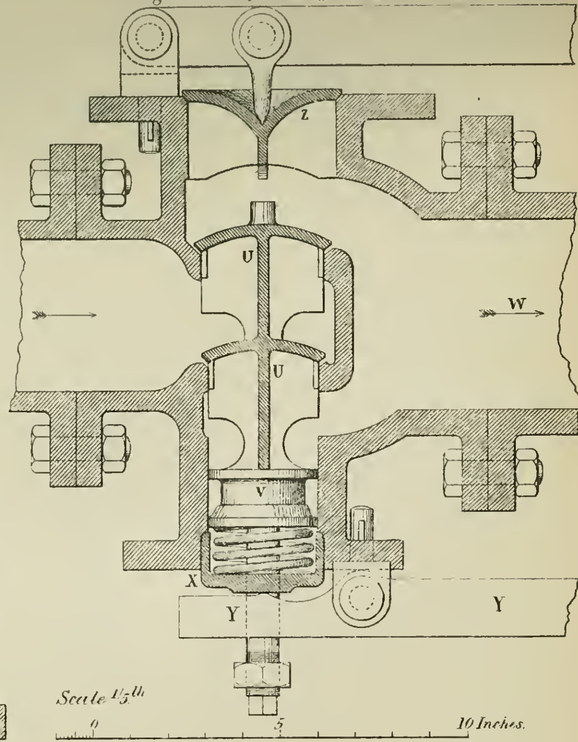


Fig. 11. *Regulating Valve.*



(Proceedings Inst. M.E. 1861. Page 30.) *Scale 1/5th.*

LOCOMOTIVE WATER SUPPLY.

Fig. 1. Longitudinal Section of Tender and Water Trough.

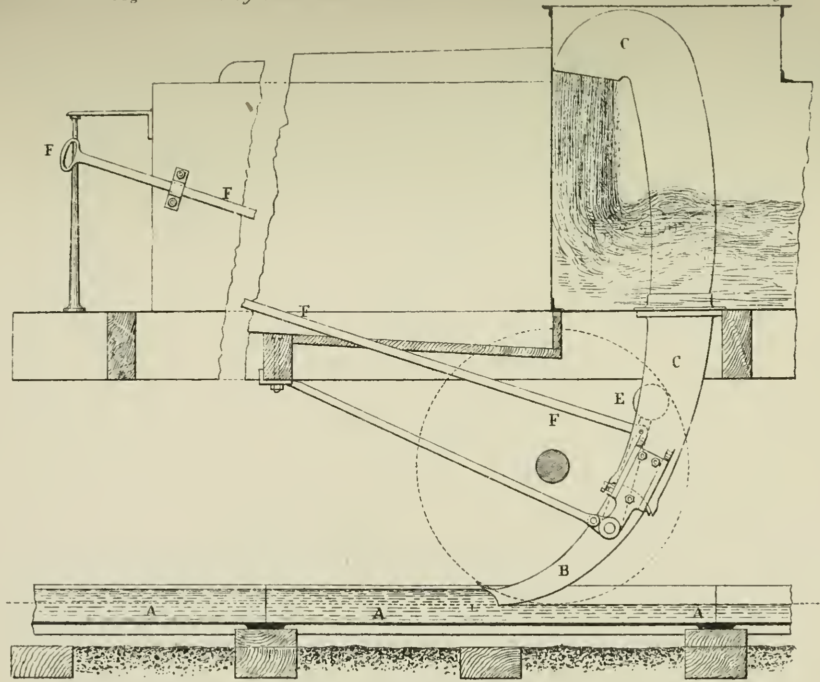
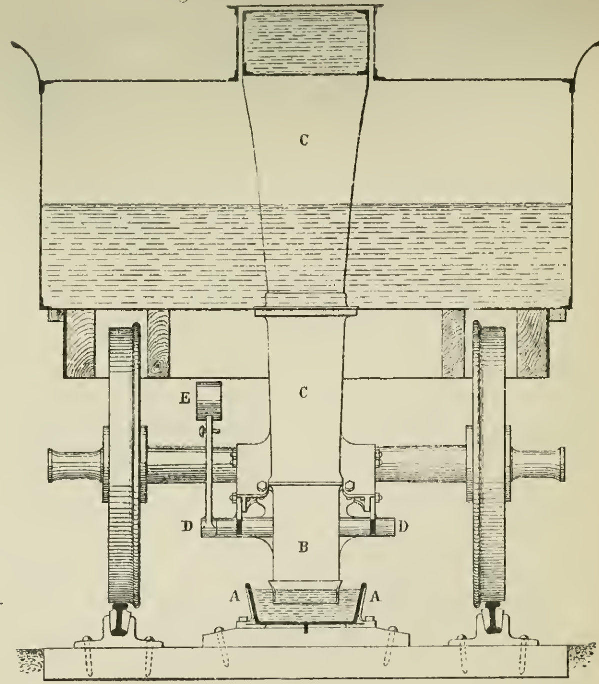


Fig. 2. Transverse Section



(Proceedings Inst. M E. 1861. Page 43) Scale 1/30th. Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

LOCOMOTIVE WATER SUPPLY.

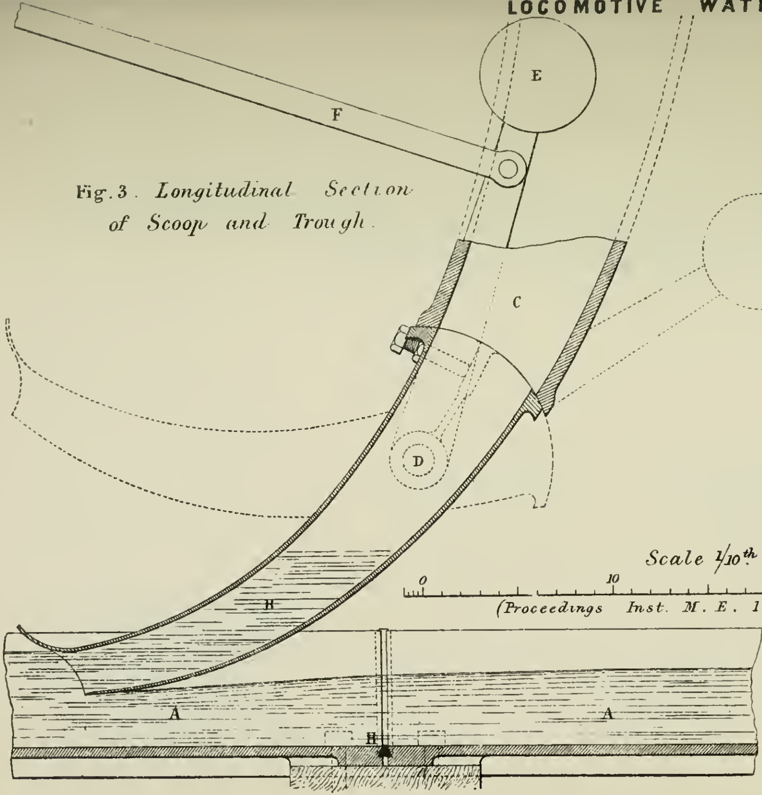


Fig. 3. Longitudinal Section of Scoop and Trough.

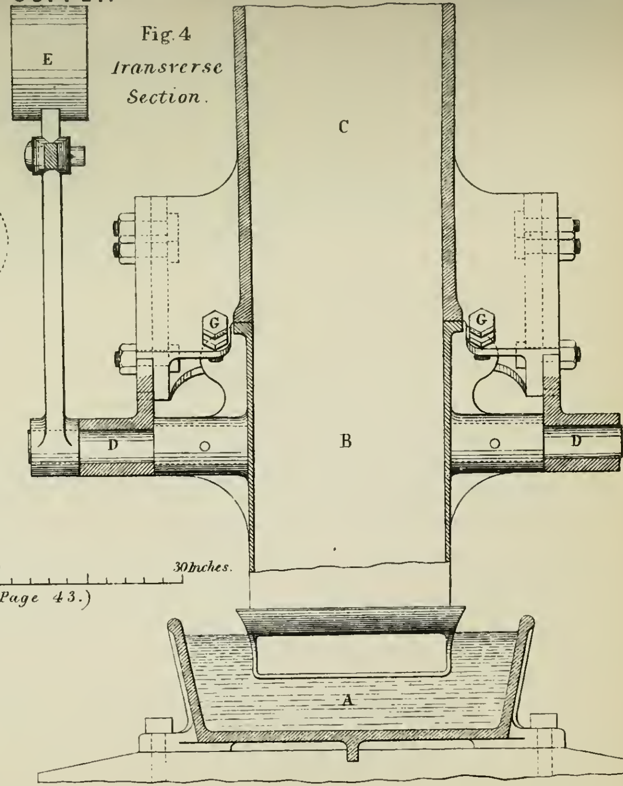


Fig. 4 Transverse Section.

Scale 1/10th.

0 10 20 30 Inches.

(Proceedings Inst. M. E. 1861. Page 43.)

LOCOMOTIVE WATER SUPPLY.

Fig. 5. *Diagram of Laying of Water Trough.*

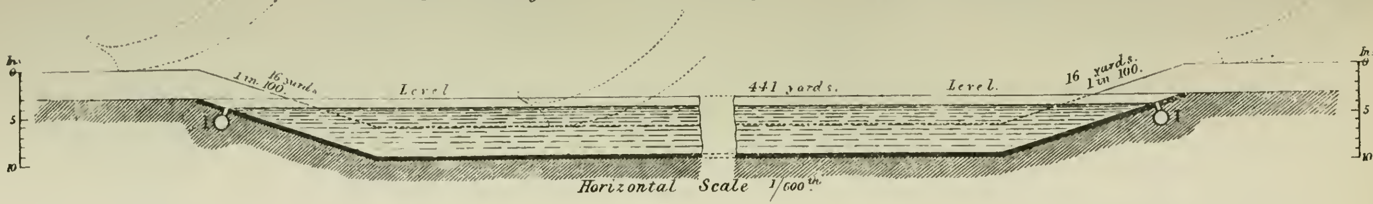
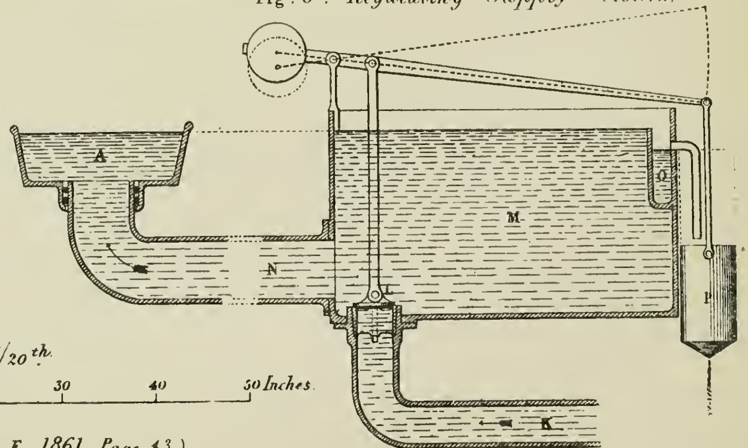


Fig. 6. *Regulating Supply Cistern.*



Ice Plough.

Fig. 7. *Side Elevation.*

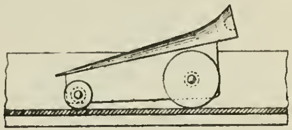


Fig. 8. *Back Elevation.*

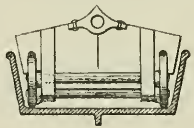
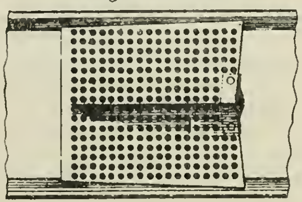
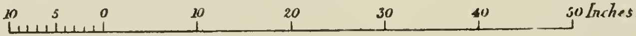


Fig. 9. *Plan*



Scale 1/20th.



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LOCOMOTIVE WATER SUPPLY.

Velocimeter.

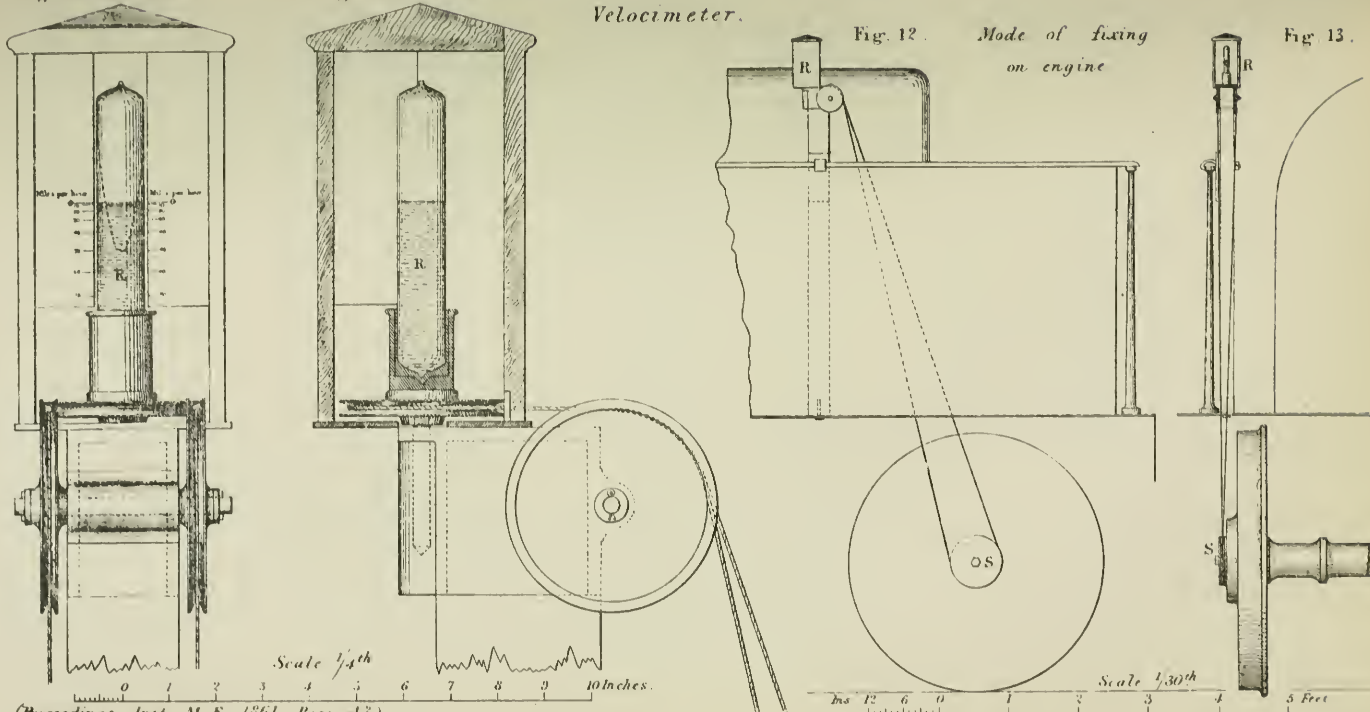

Fig 10. Front View

Fig. 11. Side View.

Fig. 12. Mode of fixing on engine

Fig. 13.

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PROCEEDINGS.

2 May, 1861.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 2nd May, 1861; Alexander B. Cochrane, Esq., Vice-President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected :—

MEMBERS.

Charles Binns,	Clay Cross.
Benjamin Dawson,	Ferryhill.
Frederick Thomas Huffam,	Bristol.
Sydney Jessop,	Sheffield.
Thomas Jessop,	Sheffield.
David Jones,	Newport, Mon.
George Low,	Kendal.
William Sumner,	Manchester.
Isaac Tipping,	Madras.
William Henry Woodhouse,	London.

The following paper was then read :—

K

DESCRIPTION OF A SELF-ACTING MACHINE FOR SPOOLING THREAD.

By Mr. WILLIAM WEILD, of Manchester.

Previous to the present century sewing thread was made up for sale in hanks, and it was not till about 1814 that the plan of winding thread on spools or reels, technically called "spooling," was introduced by Mr. James Carlile of Paisley. Thread was first wound upon spools in soft uneven and irregular layers by a common hand wheel, and the top layer was made smooth by the friction of a small piece of calico pressed against it in winding. About 1830 a spooling machine was brought into use by Mr. George Taylor of Paisley, having a single grooved guide for laying the thread upon the spool; this guide was made to traverse longitudinally by two screws geared together, so as to distribute the thread evenly upon the spool, one of the screws acting to regulate the distribution in one direction and the other in the opposite direction. The many-grooved guide and the right-and-left-handed screw were introduced about 1834.

The spools commonly used are made of wood, more or less ornamented; and some also of metal, bone, ivory, and other materials. Wood spools were first turned by hand; but the immense demand for them called attention to the necessity for self-acting machinery for producing them in a rapid manner, and this was invented in 1846 by Mr. John Clark of Glasgow. The wood is first cut into slices having a thickness about equal to the length of the intended spools; from these slices the blocks to form the spools are cut by means of a crown saw, which cuts a piece out of the slice in the form of a cylinder and bores a hole through its axis at the same time. The blocks are next supplied to the self-acting turning machine for turning them to the required shape and length, and are afterwards finished or ornamented by a milling or stamping process. One of the most improved self-

acting machines for turning spools will produce between 70 and 80 gross of spools per day, requiring the attention of one boy at wages of about 7*s*. per week.

For polishing the thread to give it a glossy appearance, it is placed in a solution of starch and then subjected to friction; in the first use of machinery for the purpose the thread was polished in the hank by rotating brushes. This is also done by means of machinery similar to that for sizing warp threads; and the last few layers of the thread wound upon spools for the market are polished in the spooling machine by extra pressure upon the thread guide.

For explaining the construction and action of the self-acting spooling machine forming the subject of the present paper, a slight reference to the process of winding by the hand-spooling machines is requisite. The most improved hand-spooling machines at the present time are placed upon long benches about three feet wide and two feet high, and driven by a shaft passing along under the bench. Each spooling head is driven by a friction clutch or pulley, which is made to engage with the clutch or pulley on the driving shaft by means of a treadle pressed down by the foot of the winder. The spooling head consists of a small headstock carrying a horizontal shaft, from the end of which projects the winding spindle that the spool is placed on. The thread guide is fixed on a sliding rod, and the alternate traversing motion is received from a shaft with a right-and-left-handed screw thread on it; the sliding rod has two arms, each carrying part of a screw nut on opposite sides of the screw shaft, one to gear with the right-handed screw thread and the other with the left-handed, so that by a slight oscillation of the sliding rod first one and then the other nut is thrown in gear with the screw shaft.

In using the spooling head the empty spool is placed upon the winding spindle, and the thread which is drawn from the end of a large bobbin is passed under the thread guide and fixed so as to wind on to the empty spool. The machine is then started, and the winder presses upon the thread guide with the left hand, giving the requisite pressure by the thumb; while the right hand reverses the traversing motion at the end of each layer of thread. When the last layer is

being wound upon the spool, extra pressure is generally given to the thread guide to polish the thread and give it the glossy appearance. When the spool is filled a nick is made in the edge of the spool, and the end of the thread secured in it. The full spool is then removed by means of a lever, as the repeated tight coiling of the thread has compressed the spool tightly upon the spindle. The winders employed in filling the spools are mostly young women, one to each spooling head or spindle.

Attempts have been made to wind thread by self-acting means on to several spools at the same time; but as a large portion of the winder's time is occupied in placing and removing the spools and in fixing the ends of the thread to them, the advantage was found insufficient to induce perseverance for overcoming the difficulties.

The entire operation of spooling thread completely by self-acting means is performed by the machine now about to be described, the invention of the writer; which accomplishes all the process of winding six spools at once, completely by self-acting means. It fixes the empty spools ready for winding, and guides the thread on to them during the winding; and when exactly 200 yards of thread are wound on, cuts a nick in the edge of the spool and draws the end of the thread into it for fastening off; then cuts off the thread and discharges the full spools, and then begins winding again on a fresh lot of empty spools.

The machine is shown in Figs. 1 and 2, Plates 14 and 15. Fig. 1, Plate 14, is a front elevation; the headstock is at the right end, and the machine has six spooling heads, each of which fills one spool at the same time. Fig, 2, Plate 15, is a vertical transverse section through the parts operating upon the spool. Figs. 3 to 7, Plates 16 and 17, show the detail of the winding, thread-fixing, and spool-changing apparatus, drawn half full size.

The thread wound upon the spools is drawn from a large bobbin stuck in the back frame of the machine, as shown in Fig. 2, Plate 15; and is guided and fed regularly upon the spool A by the thread guide B, Figs. 3 and 6, Plates 16 and 17. The spool A is driven at a speed of about 2000 revolutions per minute. The thread guide B

has spring fingers on it, through which the thread is drawn; these clip the thread with a uniform pressure and ensure its being wound with uniform tightness on the spool. The point of the guide where the thread is delivered carries a small swivel piece C on the underside, the face of which is made with fine grooves corresponding to the thickness and roundness of the thread: this grooved piece bears on the thread with a uniform pressure while in the act of being wound; and the swivel joint enables it to coincide correctly with the alternate slight inclination of the thread right and left, since the thread is wound in a right and left handed spiral alternately in the successive layers on the spool. In the ordinary hand-spooling machines the groove in the thread guide has a fixed inclination; consequently, though it smooths the thread in one layer, it slightly cuts it up and roughens it in the next. In winding the last layer of thread, the guide B is prevented from rising by a cam, and thus an extra pressure is put upon the thread which gives it the glossy finish.

The longitudinal traverse of the thread guides B for delivering the thread uniformly over the entire length of the spools is obtained as in the hand machines from a right-and-left-handed traversing screw D, Fig. 1, shown enlarged in Figs. 8 and 9, Plate 18. This screw is held stationary endways in the machine, and driven constantly in one direction while the winding is in progress. The slide rod E carrying the thread guides has two arms, each carrying a segment of a nut, on opposite sides of the traversing screw D, one to gear with the right-handed thread and the other with the left-handed; the alternate vibration of the slide rod E throws one nut into gear and the other out of gear with the traversing screw, and thus reverses the direction of traverse of the thread guides. The power necessary for making the slide rod vibrate the required amount is obtained from two flat springs F, Fig. 9, fixed parallel to the rod, which bear upon opposite sides of an arm G secured on the slide rod E: this arm is made with inclined surfaces for the springs to bear on, as shown in Figs. 10 and 11. As the slide rod traverses towards the right hand, the upper spring becomes bent by being forced up the incline on the top of the arm G, as shown in Fig. 10, while at the same time the lower spring is relaxed by the withdrawal of the incline on the bottom of the arm;

so that at the end of the traverse the upper spring has acquired sufficient preponderance of power to throw the arm over through the required vibration: and in the return traverse towards the left hand, the lower spring is bent back and the upper one relaxed, as shown in Fig. 11, ready for reversing the arm again in the same manner.

The arm G between the two reversing springs is guided by a horizontal plate H, called the shaper plate, shown black in Figs. 8 and 13, Plate 18, against which the extremity of the arm bears. In travelling towards the right, the arm bears on the top of the plate, as shown in Fig. 8, and on arriving at the edge of the plate is thrown down by the force of the top spring; it then travels back towards the left along the underside of the plate, as shown dotted in Fig. 13, and on again arriving at the edge is thrown up by the bottom spring. The shaper plate H is arranged for gradually increasing the length of traverse of the thread guides, as the winding proceeds up the bevil at each end of the spools; the edges of the plate are tapered to correspond with the shape of the bevilled ends of the spools, as shown in the plan, Fig. 9, and the plate is advanced at each double traverse of the thread guides by a ratchet wheel and cam I, Fig. 1; the reversing arm G consequently has to travel each time over a broader part of the plate, making a longer travel before it reaches the edge and reverses the traverse of the thread guides. By changing this shaper plate the machine is readily adjusted to wind any other pattern of spools. When the last layer of thread is being wound on the spools, a projecting stop J, Fig. 8, is pushed forward by the shaper plate H to catch the reversing arm G; and on the arm reaching the edge of the plate it is thrown down through only half the amount of its vibration, so that both of the traversing nuts are out of gear with the screw D, and the traverse of the thread guides consequently ceases. The reversing arm is detained in the halfway position by the stop J while the change of spools is effected; but as soon as all is ready for starting again, the stop is drawn back and the arm released, as shown in Fig. 13, throwing one of the traversing nuts into gear with the screw.

When the winding of the last layer of thread is completed, the whole of the winding motion is instantly stopped dead by the appli-

cation of a break K, Fig. 2, Plate 15, consisting of a leather band, shown by the strong black line, passing round a pulley on the main driving shaft of the winding apparatus; the band is suddenly tightened on the pulley by a lever and cam, and holds all the winding motion quite stationary while the operations of fastening the threads and changing the spools are performed. As soon as the winding is stopped, the incision knife L, Figs. 3 and 7, for cutting the nick in the edge of the spool, descends and makes the cut, as shown in Fig. 4, Plate 16, while the point of the spring M fixed on the inner side of the knife presses on the spool close to the last coil of thread, preventing it from uncoiling, and directing the thread into the nick; the thread guide B having previously risen clear of the spool, as shown in Fig. 3. The thread-pushing finger N is then drawn to the right, and pushes the thread past the edge of the spool and round the spring point M, as shown in Fig. 7. The hook O now descends and catches the thread. On the side of the hook next to the spool a knife edge P turned upwards is fixed, against which the hook is pressed by a pinching spring Q on the other side. As the hook descends it first pulls the thread into the nick in the spool, and then draws it past the knife edge, which cuts it off. The loose end of the thread is meanwhile held tight between the hook and the pinching spring Q, as shown in Fig. 5, Plate 16, while the full spool is discharged and replaced by an empty one.

For changing the spools the winding spindle R and back centre S, Fig. 6, Plate 17, are both withdrawn by cams, and the full spool drops into the box below; the cradle T containing the empty spool is now raised by another cam, and the winding spindle R advanced again ready to receive it. The spool is pushed on to the spindle by the return of the back centre S, and is pressed up against a shoulder on the spindle R with driving points inserted in its face for making the spool revolve with the winding spindle. The loose end of the thread held fast between the hook O and pinching spring Q, as shown in Fig. 5, Plate 16, is in such a position that it gets caught between the spool and the shoulder of the winding spindle, and is thus secured ready for starting the winding.

The thread guides B having left off work on the full spools at the extreme end of their longest traverse have now to be brought back through the length of the bevil end of the spools: this is done by a sliding wedge acting on the end of the slide rod E that carries the thread guides; and the shaper plate H is withdrawn by the same movement. The thread guides are then lowered on to the spools, the break taken off, and the winding apparatus started again, when the winding proceeds as before till the spools are filled. All the movements necessary to make the required changes are produced by the machine itself, by cams arranged for the purpose, without anything being done by hand by the attendant, who has merely to supply the empty spools into the cradles while the winding is going on, renew the large thread bobbins when emptied, and join up any broken thread that may occur.

The three sliding rods U, Figs. 3 and 6, Plates 16 and 17, which give the longitudinal movements to the thread-pushing finger N, the winding spindle R, and the back centre S of each of the six spools in the machine, pass right through the whole length of the machine, as shown by the strong full and dotted lines in Fig. 1, Plate 14, having arms fixed upon them to give the required movements to the several parts. Each arm is fixed upon its own slide rod by a set screw, and has holes in it through which the other two rods slide freely; this avoids having to make the arms cranked to clear the rods, and the rods thus serve the double purpose of communicating the longitudinal movements and of also acting themselves as guides to the arms upon them, thereby giving great steadiness of motion and compactness of construction. Each slide rod is worked by a separate cam, as shown in Fig. 1, the movement of each being entirely independent and distinct from those of the other two.

Of the three driving pulleys V at the right end of the machine, Fig. 1, Plate 14, the outside one drives the whole of the winding apparatus and the screw that gives the traverse to the thread guides; and the inside pulley drives the whole of the change cams which perform the several operations that take place whilst the winding is stopped. The driving belt is traversed backwards and forwards from

one pulley to the other by a cam driven from the middle pulley of the three; this pulley gears with an intermediate shaft, on which is a friction wheel covered with leather, running against another friction wheel on the cam shaft, as shown in Figs. 12 and 13, Plate 18. The intermediate shaft W is kept perpetually running, the driving belt being always partly on the middle pulley; but the friction wheel X on the cam shaft has its circumference notched away at two opposite points, so that it makes only half a revolution at a time and then loses the bite of the friction wheel W. One half revolution of the cam shifts the driving belt from the outside driving pulley to the inside one, and the other half revolution shifts it back again; and the same shaft X carries also the cams that put on the breaks for stopping those parts of the machine that are thrown out of gear by the change of driving belt. An escape plate on the cam shaft has two stops upon it, shown dotted in Figs. 12 and 13, which are caught at each half revolution by a catch on the escape lever Y, so that the cam shaft X is stopped dead the instant that the friction wheels lose their bite. The upper end of the escape lever Y is attached to the shaper plate H that regulates the traverse of the thread guides, whereby the change of belt is made dependent on the completion of the other movements of the machine.

As the cam shaft X, Plate 18, is stopped at the time when the friction wheels have lost their bite of one another, as shown in Fig. 12, it requires a slight turn to start it again till the wheels bite; this is given by the maintaining spring Z, which bears against two studs on the escape plate, and turns the notched wheel X on far enough to enable the leather friction wheel W to bite and perform the half revolution, as shown in Fig. 13. This maintaining spring corresponds to the maintaining spring in a clock, which keeps the clock going during the time of winding up.

The order in which the several operations performed by the machine take place is explained by the diagrams in Plate 19, which show the forms of the changing cams and their relative times of action, and the manner in which the successive movements of the machine are arranged to follow and take up the work one after another,

after the winding of the thread is completed. In these diagrams the path of each cam is delineated on a straight line as a datum line, which may represent the centre line upon which the path of the cam is to be constructed, its length corresponding to the circumference of the cam in that line. The vertical lines are 30 degrees apart, the first and last, marked respectively 0° and 360°, representing the same part of the cam. The circles represent the rollers which the cams act upon, and are all supposed to travel in the direction of the arrow. Fig. 14 represents the cam for lifting the thread guide B, Fig. 3, Plate 16; Fig. 15 represents the thread-fixing and cutting cam; Fig. 16 the cam which makes the incision in the edge of the spool for securing the end of the thread; Fig. 17 the cam which pushes the thread to one side; Fig. 18 the cam which shifts the back centre S; Fig. 19 the cam which shifts the winding spindle R; and Fig. 20 the cam which works the feeding cradle T.

When the filling of the spools is taking place, the driving belt is then working upon the outside and middle driving pulleys V, Fig. 1, driving the whole of the winding and traversing gearing. The thread guides rise as the spools fill, till the last layer but one, when their rise is obstructed by a cam which gives extra pressure to polish the thread; but by the time the last layer is wound on the spool, the cam has turned on far enough to remove the obstruction to the rise of the thread guide. At the same time the escape plate X, Fig. 12, is released, and the belt-changing cam causes the driving-belt to be traversed on to the inside driving pulley, for fastening off the thread and changing the spool; and at the same instant lifts the break off this pulley, and puts on the break K, Fig. 2, to stop the winding apparatus.

At the 5th degree of rotation of the cam shafts the thread guide begins to lift clear of the spool, as shown in the diagram, Fig. 14, Plate 19, and has finished lifting at the 25th degree, and then becomes stationary. The hook for drawing the thread down into the nick on the spool begins to rise at about the 12th degree of rotation, Fig. 15, and has attained the greatest height at the 55th degree, and then remains stationary for a few degrees. The incision knife begins to descend at the 15th degree, Fig. 16, and has made the cut

in the edge of the spool at the 40th degree, and then remains stationary, while the spring point connected with it presses on the spool and prevents the thread from getting unwound. The thread-pushing finger begins its longitudinal movement at the 25th degree, Fig. 17, and ends at the 65th degree, when it has drawn the thread round the spring point and past the end of the spool; the finger then remains stationary, and at this point the hook begins to make the descending movement, Fig. 15, having caught the thread pushed past the edge of the spool by the finger. At the same time that the hook begins to descend, the incision knife begins to rise, Fig. 16, and has risen sufficiently to lift the knife out of the incision at the 85th degree of rotation, when it remains stationary till the 95th degree, to give time for the thread to be drawn into the incision by the descending movement of the hook. The knife then begins to rise again and lift the spring point from off the spool, the ascending movement ending at the 105th degree; and having completed its work it then remains in its original position clear of the spool during the rest of the revolution, as shown in Fig. 6, Plate 17. The finger remains stationary between the 65th and 92nd degrees of rotation, Fig. 17; and having completed its work retires between the 92nd and 145th degrees to its first position.

At the 140th degree of rotation the back centre begins a short backward movement, Fig. 18, which ends at the 150th degree; the object of which is to give clearance so that the full spool may be freely discharged. The winding spindle also begins its movement at the 140th degree, Fig. 19, to withdraw the spindle from the full spool, which is pushed off it by coming against a projection on the bush forming the bearing of the shaft that drives the spindle, as shown at R in Fig. 6, Plate 17. The winding spindle is completely withdrawn at the 195th degree, Fig. 19, and then remains stationary till the 215th degree, when it begins to advance again into its first position, at which it arrives at the 275th degree, and is now again in its winding position, ready to receive the fresh empty spool. At the 185th degree the back centre begins to be withdrawn, Fig. 18, so that the empty spool may be brought into the feeding position, and it is completely withdrawn at the 240th degree, when it becomes stationary.

At this point the feeding cradle containing the empty spool begins to rise, Fig. 20, and has brought the axis of the empty spool opposite to the winding spindle at the 270th degree of rotation, when it becomes stationary. The back centre having remained stationary till the 275th degree, Fig. 18, begins to make the return movement, advancing again into its first position, which it attains at the 325th degree; during this movement it pushes the empty spool from the cradle on to the winding spindle, the thread being caught and pinched between the end of the spool and the shoulder on the winding spindle. The feeding cradle which has been stationary to the 315th degree, Fig. 20, is then lowered again to its first position, at which it arrives at the 345th degree. The hook which has been stationary to the 342nd degree, Fig. 15, holding the end of the thread, begins then to rise to its first position, at which it arrives at the 352nd degree, when the end of the thread is liberated from the pinching spring; and the thread guide which has been stationary to the 325th degree, Fig. 14, begins to lower, the cam ceasing its action at the 355th degree of rotation.

The operations of changing the spools are now entirely completed; and by the time the cam shafts have completed their 360th degree of rotation, a crank upon one of them causes the escape plate X, Fig. 13, to be liberated, and the belt-changing cam immediately turns and traverses the driving belt on to the outside pulley which drives the winding gearing, applying the break to the inner pulley, and taking off that which stops the winding. The filling of the spools then commences, and the same series of operations are repeated for each set of spools filled with thread.

To work these self-acting spooling machines it is important that the spools should be of uniform size and shape. Spools turned by hand would not be sufficiently uniform in this respect; and when this machine was first introduced machine-made spools were not as uniform in size as they have since become. But what is wanted is a uniform standard size and shape for spools: at present each maker has his own size and shape, and they are not constructed according to any definite rule. A uniform standard would be a great advantage in

the self-acting spooling machine, as the same shaper plate could be used for all the spools: the machine however admits of being instantly changed and adapted to any other form of spool, by simply removing the shaper plate and substituting another of the new form. After an examination of a great number of specimens, the best proportions for spools are considered to be the following:—the diameter of the heads equal to three fourths of the length; the diameter of the barrel half the diameter of the heads or three eighths of the length of the spool; the length of the barrel half the length of the spool; and the bevil at each end at an angle of 45 degrees, thus leaving a margin at each end of the spool of one sixteenth of the length of the spool. The angle of 45 degrees is most convenient for the thread guide, and gives sufficient strength in the heads of the spool: where the angle is more acute the heads are thin and the pressure of the thread frequently breaks them off from the barrel. It is also suggested that each size of spool shall be numbered and known by a number, and that this number shall represent the length of the spool in tenths of an inch; so that when the number of a spool is known its size and proportions will be known also.

The diagram Fig. 21, Plate 19, is a scale for constructing the proposed standard spools. The horizontal line is divided by vertical lines at equal distances apart; and at the last vertical line, say the twentieth, intended to represent the largest spool, a point is marked off representing the entire length of the spool or 20 tenths of an inch. This vertical line is then divided into the proportions for the spools as above suggested; and straight lines are drawn from the several points thus obtained to the other end of the horizontal line, whereby the rest of the vertical lines are all divided into similar proportions; and each vertical line being numbered from the small end of the scale will thus have upon it all the dimensions for that number of spool. Upon the diagram, spools are represented constructed according to the scale from the smallest up to the largest size.

The self-acting spooling machine will fill one set of spools in about one minute, placing 200 yards' length upon each spool; occupying

about 54 seconds of that time in winding and about 6 seconds in changing the full spools for empty ones. One machine will fill on an average 18 to 20 gross of spools per day of ten hours, including all stoppages for supplying thread &c. It requires the attention of one person, but there is no skill necessary as in hand-winding; for a person who has never been employed in spooling thread and has never seen a similar machine before will learn all that is required in a few days. With the hand-spooling machines one winder can fill 3 gross of spools per day on an average, placing 200 yards on each spool, at wages of from 6*d.* to $7\frac{1}{2}$*d.* per gross, and can earn from 9*s.* to 10*s.* per week. One self-acting spooling machine of six heads will thus do the work of six hand-spoolers; so that, omitting the consideration of skill, five sixths of the labour in spooling sewing thread is economised. And this is not the only advantage, but there is another important saving: of the same quantity of material supplied to hand spoolers and to the self-acting machine, the latter returns 2 per cent. more than the former, showing that more waste is made in hand spooling than by the machine.

In conclusion, to give an idea of the importance of the machine in money value, it may be stated that if generally adopted it will effect a saving in labour and material of £100,000 per annum, the interest of a capital of two millions. The extent and importance of the trade may be judged from the fact that, according to a moderate estimate, upwards of three thousand persons are employed in the United Kingdom in spooling sewing thread by the hand machines: and they produce between three and four hundred millions of spools per annum, of an average length of 200 yards each, and each thread averaging four single threads.

Mr. Weild showed a working model of the spooling machine, illustrating the successive movements performed in the process of winding the thread and changing the spools; and also specimens of the more important parts of one of the machines. He described the early plans of winding thread in balls, and exhibited at work an

original hand-balling machine constructed by a Frenchman in Manchester about the year 1800 and believed to be the earliest machine for the purpose, and another constructed by Brunel several years later; together with a specimen of one of the present hand-spooling heads.

The Chairman asked how long the self-acting spooling machines had been at work, and how many of them were in operation.

Mr. Weild said the first experiments in spooling by a self-acting machine were made about three years ago, and the machine had now been about 18 months at work; there were already about 30 of the machines altogether at work successfully in different parts of the country, principally at Huddersfield, Manchester, Derby, Paisley, and Glasgow. The rate at which the work was done was greatly increased as compared with hand winding, the hand-spooling machines winding only 3 gross of spools each in a day, while the self-acting machine with six heads wound 20 gross per day, and sometimes as many as 22 gross, putting 200 yards of thread on each spool.

The Chairman enquired what was the cost of the machine.

Mr. Weild said the cost of the machine with six heads for winding six spools at a time was about £100. The most expensive portions of the machine, the winding and changing gearing and the several cam motions, were just the same whether there were six heads or only one; and therefore a large machine was not much more expensive than a small one.

Mr. J. Anderson asked how the length of thread wound on the spools by the self-acting machine was determined, and whether any variation could be made in the length by winding it slacker in some of the layers.

Mr. Weild replied that the machine was adjusted for any length and form of spool by simply changing the shaper template that regulated the travel of the thread guide; and the number of teeth in the ratchet advancing the shaper template determined the length of thread wound, by fixing the number of layers put on the spool. A slight variation in the tension on the thread in winding would produce a difference of a yard in the length of 200 yards put on the spool; but in the machine the thread was delivered on to the spool through

the spring fingers of the thread guide, the pressure being adjusted by a set screw, which gave it a uniform degree of tension throughout the whole winding. The machine must consequently always put the full length of thread on the spools, and there could be no tampering with it. In hand-winding the thread might be put on carelessly in the inner layers without being even and solid, and then smoothed down in the outside layers by extra pressure with a smoothing pad, so as to look well externally; but in the present machine the winding must be done equally well all through, the whole of the winding being thus equal to the best of the hand-winding. He showed specimens of spools wound by hand-spooling heads and by the self-acting machine; and of winding done by eye alone without a guide for the thread, but simply smoothed over in the last few layers.

The swivelling grooved guide delivering the thread on to the spool was a practical improvement of considerable importance in the self-acting machine; for though only a very slight alteration in the obliquity was required, it was still enough to make the difference between smooth and rough winding; and the machine was nearly being abandoned at first on account of the difficulty of winding the thread with a fixed guide. In hand-winding the obliquity of the guide was altered by a slight twist of the hand to agree with the alternate inclination of the thread, so that the smoothness of the winding was entirely dependent on the skill of the winder; but in the machine the change of direction of the thread itself was sufficient to turn the swivelling guide through the angle required, and the winding was consequently as smooth and good in all the layers as in the last. He showed one of the hobs or dies for cutting the grooves in the thread guides, which were of very fine make and of various sizes, from 180 grooves per inch down to 40, according to the thickness of the thread to be wound; and the groves were made truly semicircular at the bottom, in order to keep the thread round and not flattened by the pressure of an angular groove, as it was considered damaged if flattened.

Mr. J. Anderson enquired what sort of wood was used for making the spools, and whether it was steamed or prepared in any way for cutting them out.

Mr. Weild said the spools were made of ordinary birchwood, which was only dried and cut up by a circular saw into transverse slices like the specimen shown, corresponding to the length of the spools; sometimes it was steamed beforehand, when in a greener state than usual. The demand for spools was so great that it had occasioned a scarcity of birchwood in this country; and a large Paisley manufacturer had imported turned spools from America cheaper than they could be made here, although with the present turning machines a boy at 7s. a week could produce 80 gross of spools per day. The slice of birchwood was placed under a machine like an upright drill, having a rapidly revolving crown saw with a drill in the centre, which cut out cylindrical pieces of wood of the size of the spool, with a hole ready bored through the centre. These were put in the hopper of the turning machine by a boy, and fed to a lathe having a set of cutting tools fixed in slides, which came into action successively to turn the sides and ends of the spools; one revolution of a cam then completed the turning of the spools. Some of the turning machines were only partly self-acting, having the cutting tools brought up by a hand lever.

Mr. J. Anderson supposed the spools must be driven very quick for cutting the soft wood smooth without splitting.

Mr. Weild said the speed was so great that, although the wood was cut crossways of the grain, the whole of the cutting was thrown off in a single continuous turning, like a shaving from a plane, down to the very bottom of the spool, instead of in a number of small turnings.

Mr. E. A. Cowper thought the two reversing springs arranged in connection with the shaper template for reversing the travel of the thread guides formed a particularly ingenious contrivance in the machine: as the tracing finger moved along, it charged one of the springs gradually, whereby it was suddenly thrown down or up at the end of its travel across the shaper template, and it then charged the other spring similarly on its return; the same instrument being thus made to move first up and then down by entirely self-acting means, without any driving motion being communicated to it, except the simple reciprocating horizontal movement received from the traversing screw. He enquired whether the contact shaft at the back of the

machine made any of the changes required in the winding or spool-changing movements.

Mr. Weild said the only purpose of the notched wheel was to shift the driving belt from the outside pulley driving the winding apparatus to the inside pulley driving the change movements, and back again alternately. The arrangement was commonly known as Roberts' contact pulley, originally used in the self-acting mule, for making intermittent movements with alternate intervals of rest.

Mr. F. J. Bramwell observed that neither of the three driving pulleys was really a loose pulley, and since the middle one had the strap always on and was consequently always running, the driving power was always ready for shifting the belt at the instant when required; so that the continuous driving of the machine was kept up without intermission, though each portion of it stood still in turn.

The Secretary had seen the self-acting winding machines at work at Huddersfield, and could confirm the statements as to their satisfactory working: the great speed of winding, and the effective manner in which the winding was suddenly stopped dead when completed, were very striking; and also the steady and gradual action of the succeeding change movements in fastening off and cutting the thread and changing the spools. The working of the machine appeared very perfect and complete, and was stated by the proprietor to be thoroughly successful.

Mr. Weild remarked that one great difficulty that had been experienced at first in getting the machine to work was to stop the winding at the right moment when the spools were full. In winding by hand, the motion being controlled by the winder could be gradually retarded, so as to stop exactly at the end of the last layer of thread; but in the machine the great momentum of the winding parts revolving at such a high speed rendered it impossible to stop at the right point, until the powerful friction break was adopted, consisting of a strap passing round a friction pulley of large diameter. By this means the winding was stopped dead at the proper point, but without any shock, and the gearing and spools were all held quite stationary while the change movements were performed.

The Chairman moved a vote of thanks to Mr. Weild, which was passed, for his very interesting paper, and the trouble he had taken in preparing the drawings and model by which its ingenious action was exhibited so completely.

The following paper was then read:—

ON A NEW MODE OF COKING IN OVENS, APPLIED TO THE STAFFORDSHIRE SLACK.

By Mr. ALEXANDER B. COCHRANE, of Dudley.

Many varieties of Coke Ovens have from time to time been invented with a view to economise the cost of coking, which have met with variable success; and attempts have recently been made to perfect the adoption of flues underneath the floor of the ovens, which were tried so long ago as 1853 by Mr. Joseph Dunning and have since been attempted frequently but with only partial success. The subject of coking has a most important bearing upon railways especially; and if coke could be obtained at a cost approximating more nearly to the price of large coals than can possibly be the case under the ordinary system of coking whereby little more than a yield of 50 per cent. is obtained, the advisability of again reverting to coke in locomotives instead of coal would be considered, and would probably be judged expedient.

In the ordinary plan of coking, the oven in which the process is performed is a round chamber about 10 feet internal diameter, as shown in Fig. 7, Plate 22, the floor of which slopes gently from the back to the front; the oven is covered in by a dome springing at about 4 feet from the floor and rising to about 8 feet at the highest point. At the centre of the dome the charging orifice is situated, which serves as a chimney in the simplest form of oven, and as the entrance into the general flue of a series of ovens where a separate chimney is employed. The coke is drawn out through the door in front of the oven, and in some instances the coals are also charged through the door. In such an oven, whether it be open-topped, or whether the gases and smoke instead of being allowed to escape immediately into the atmosphere are conveyed along a general flue to a suitable chimney, the process of coking is carried on from the top of

the coals only, travelling downwards until it reaches the floor of the ovens. But the coking could not be carried on without a considerable quantity of air being admitted during a certain period at least of the process; and the fact is that the coking is effected at the expense of the combustion of a certain percentage of the coke which the charge of coals ought to yield. Were not air admitted, the process would stop; and as it is, the ovens are subject to great irregularities from the uncertain draughts in variable states of the atmosphere. This is evidenced by the fact that if the draught of an oven is interfered with the oven does not get "burnt off" as it ought to be, requiring perhaps a day longer to be completed or even more; and when the oven is drawn it will be found that the coke is accompanied with the objectionable appearance due to what are called "black ends" or partially coked coals. This great evil has been in a measure corrected by the adoption of a tall chimney to a series of ovens, but in that case arises another objection: in a long series of ovens it is difficult to make the influence of the chimney felt throughout; and consequently of the two systems the original one is still preferred in some instances.

In connecting a chimney to a series of ovens the arrangement found best is to place say 48 ovens in a double row of 24 each, back to back, with a central flue passing between the two rows into a chimney occupying a central position in the block of ovens. But even in such an arrangement, where the farthest oven is separated by only 11 intermediate ovens from the central chimney, it is found impossible to prevent the speedy burning off of the oven nearest the chimney and the tardy burning off of the farthest, the intermediate ovens varying in their regularity according to their distance. It is said the oven nearest the chimney is capable of being burnt off without intentional admission of air, which in the other ovens is usually allowed to enter by only partially closing the door; but the real fact is that the draught of the chimney exercising its greatest force on the nearest oven draws in a quantity of air, imperceptibly though not the less certainly, through the imperfect joints of the temporary door and of the external and internal masonry; and each oven only apparently requires more air as it recedes from the chimney. At the Gloucester railway station the writer believes it was attempted several years

ago to correct this evil by arranging a series of ordinary ovens in a circle around a central chimney, and no doubt the difficulty as regarded the draught was removed; but from some cause or other the whole system is now swept away. Such an arrangement however as that of a central chimney with the ovens arranged in a circle round it would evidently constitute a marked improvement so far as regularity of draught for each oven is concerned; but it is equally clear that with the ordinary construction of ovens as above described much ground would be sacrificed by such a plan.

The yield of ordinary coke ovens rarely exceeds 50 to 52 per cent. of the coal supplied. The experiments which have been made to bring about the adoption of flued ovens have pointed to the importance of making use of the waste heat from the ordinary coke ovens to assist in the process of coking. Indeed all flued ovens have one common object: to make the waste gases circulate in flues either beneath the floor of the oven, where they are ignited by suitable admission of air; or, as in one instance, around the top, sides, and floor of the oven. As may be supposed, the rapidity with which the coking is performed is greatly increased, and the non-admission of air to the contents of the oven is a source of great increase in the yield: but the wear and tear on this class of ovens is excessive. In one instance, where the waste gases are made completely to envelope the oven, the wear and tear amounts to no less than 6*d.* per ton of coke produced; and in a recent plan the writer understands the flues underneath the floors of the ovens are in a very short time so destroyed that the oven must be laid off for repairs, far too frequently to make the plan commercially successful.

The plan of coke oven forming the subject of the present paper, the invention of Mr. Henry Eaton of Bordeaux, is believed to fulfil the requirements of a good coke oven more completely than ovens on the ordinary plan or those having flues underneath the floor. About the middle of last year the writer, having to decide on the class of oven to be adopted at his Tursdale Colliery in the county of Durham, after a careful investigation into the merits of various plans determined to build an experimental block of 12 ovens on Mr. Eaton's plan at

the Woodside Iron Works, Dudley, with the intention not only of testing the value of the ovens for coking North country coal, but also of trying what could be done in coking the intractable slack of the Staffordshire Thick coal, the "fine" of which has hitherto been thrown away as waste in very large quantities. The success was so far complete that it was both decided to adopt this system at the Tursdale Colliery, where two blocks of 12 ovens each are now in operation on this plan and a third in progress; and a second block has also been erected at Woodside, which has been at work for two months.

The new ovens are shown in Plates 20, 21, and 22. Figs. 1 and 2, Plate 20, are a general elevation and plan of a single block of the ovens; Fig. 3, Plate 21, is a sectional plan to a larger scale, and Figs. 4 and 5, Plate 22, are longitudinal and transverse sections of the ovens.

The ovens, twelve in number, are arranged in the form of a circular block, as shown in Figs. 1 and 2, Plate 20, of 44 feet diameter, round a high chimney in the centre, which causes the draught to be equal upon all the ovens, so that the coking proceeds in all alike with equal regularity. Each oven A, Figs. 3 and 4, opens at the back by a flue into the regulator B, from which is a smaller flue leading into the chimney C. At its junction with the oven the size of the flue is about 18 inches square, reduced at the regulator B to 8 inches square, and at the foot of the chimney it is only 6 inches square. The regulator B is a rectangular chamber covered by a moveable plate perforated with holes for the admission of air to the gases disengaged in the process of coking. The square chimney C is divided at the base by diagonal partitions D, Fig. 3, rising a little above the flue levels, the effect of which is to distribute the draught of the chimney uniformly over the twelve ovens in four sets of three each. The flues do not enter the chimney at the same level, but the middle one in each set of three rises above the two on either side, and thus space is economised in the size of the chimney at the base. The top of the chimney is 3 feet square inside, but this is larger than necessary, and it need not exceed 2 feet 7 inches square. The chimney is lined with firebrick for 12 or 15 feet of its height

from the base, to protect the red brickwork from the intensity of the combustion which there takes place. It will thus be seen that the arrangement of a central chimney and its division at bottom by four partitions creates a most uniform draught in each oven of the block, and this uniformity is one of the most important elements to be secured in coking.

The chimney and ovens rest on a foundation E, Fig. 4, Plate 22, made up of cinders and dry rubbish free from any combustible ingredients, well rammed in to secure solidity, over which is laid about 9 inches of concrete. The whole block of ovens is contained by brick walls bound together by bolts and straps, the latter being wrought to the form of the door frames, which are thereby held in their places. Each oven is covered in by an arch, shown in the transverse section Fig. 5, every portion of which is an arc of the same circle. The turning of the arch has been found to be a matter of some difficulty, to ensure permanency; but has been satisfactorily accomplished in the following manner. To make a perfect skewback for this arch, the angle at which the arch beds on the partition walls of the ovens should vary at every point of the walls, on account of their diverging from one another, as they all radiate from the centre of the block. But it has been found best to adopt a medium angle throughout, and cut the last arch bricks on each side of the oven to bed properly to their place. The rest of the arch bricks are all bedded in planes parallel to a centre line through the middle of each oven: so that after starting from the skewbacks, as the lines of bedding planes lengthen and approach the centre, they leave a parallel strip the whole length of the oven and the arch is easily keyed in. This done, the centering being constructed in three convenient parts can be easily taken to pieces and removed through the mouth of the oven.

The charging of the ovens, where one kind of coal alone is used, is done by wagons holding about 10 cwts. of coal each, which run upon a circular railway F, Fig. 4, Plate 22, on the top of the ovens. When the charging is completed, the moveable hopper G is removed, and the hole in the roof of the oven closed by a large slab and luted all round to make it air-tight. Where a mixture of coal is needed it is usually more convenient to fill at the mouth of the ovens. The

plan, Fig. 2, Plate 20, shows half the block of ovens with the railway for charging through the roof of the ovens, and half without the charging orifices in the roof. The progress of the coking can at all times be inspected through a sight hole in the top of the door of each oven, which is closed by a small fireclay plug. When completed the coke is withdrawn very easily from the ovens, as the partition walls are radial and diverging from each other. For watering the coke previous to drawing, a water main H, shown in section in Fig. 4, encircles the block of ovens, having suitable standards fitted with india-rubber hose pipes; at the end of the hose is attached a long gas tube which is put in through the mouth of the oven and moved about to direct the water over the surface of the coke. For facility of handling the tube and working the tools used in drawing the coke, a small portable crane I, Fig. 1, is provided, easily shifted by a couple of men, having a double hook roller, shown in Fig. 6, Plate 22, over which the tools move easily.

The mode of working these ovens is in the first place to dry them off in the usual way, which takes four to six days from the first lighting of the fires. When sufficiently heated, the ovens Nos. 1-4-7-10 are cleared of ashes and charged on the first day, the heat being purposely kept up in the rest of the ovens till they are in their turn charged. On the second day the ovens Nos. 2-5-8-11 are charged, and on the third Nos. 3-6-9-12. By this plan of charging the heat of Nos. 12 and 2 is assisting to impart heat through the partition walls to No. 1 between them; the same takes place with Nos. 4-7-10, each between a pair of warm ovens. For 24 hours therefore Nos. 1-4-7-10 have the advantage of adjacent heat, by which time they have acquired sufficient temperature to permit of the drawing and charging of the one set of adjacent ovens Nos. 2-5-8-11 on the second day without injury. Indeed the first ovens have acquired a sufficient degree of temperature to assist in starting the operation of coking in the ovens charged on the second day. The same remarks apply to the charging of ovens on the third day, those of the first and second day both now assisting to start the coking process in Nos. 3-6-9-12 charged on the third day. For 24 hours the ovens charged on the first and second day are now reacting upon one another, whilst those

charged on the third day are being urged forward to a degree which will enable them on the fourth day to permit of the drawing and recharging of Nos. 1-4-7-10.

In applying the new plan of ovens to the coking of the fine slack of the Staffordshire Thick coal, it is mixed either with bituminous slack from South Wales or with a smaller portion of pitch, in order to impart the necessary caking quality, the want of which has rendered the Staffordshire slack incapable of conversion into coke by any plans previously tried. In either case the requisite binding property is now obtained, and the coke is produced in lumps of large size and excellent quality, and is found of particular value in the blast furnace. With a mixture of 45 per cent. of Staffordshire slack and 55 per cent. of bituminous Welsh slack, the yield regularly obtained in the first block of ovens at Woodside, which is only 42 feet diameter, has amounted to from 55 to 60 per cent. of coke. With a mixture of 75 per cent. of Staffordshire slack and 25 per cent. of pitch, the yield has been from 50 to 53 per cent. of coke. The fluctuations in the yield arise from the variations in the quality of slack obtained from different places, some requiring more bitumen to bind it together. Where the binding is not perfect, considerable waste ensues in drawing the coke. To correct this has been the object of some recent experiments, in which a mixture of 44 per cent. of Staffordshire slack with 44 per cent. of Welsh slack and 12 per cent. of pitch has been used, resulting in a regular yield of from 60 to 65 per cent. of coke. Specimens of coke are exhibited to illustrate the respective binding power of the different mixtures described. The best yields however, as may be supposed, are obtained from coals which contain a sufficient proportion of bitumen to secure binding without admixture: such as the bituminous or caking coals of Durham, Newcastle, and South Wales, from which results of 67½ to 70 per cent. yield of coke are uniformly obtained in these ovens. These results have been obtained from coals supplied from the Brithdir Colliery in South Wales, Pease's West Colliery in Durham, and the Tursdale Colliery in Durham.

In the first block of the new ovens at Woodside, which gave the yields of coke above stated from the Staffordshire slack, the partition walls between the ovens were built 9 inches thick. It is evident however that the thinner the partition walls the more perfect is the communication of heat between the ovens; and the writer found in the erection of the first block of ovens that 9 inches make too thick a wall. The consequence of this mistake was that the quantity of coke produced was not so great as expected, since it was absolutely necessary to assist the progress of the coking by a large admission of air. In France, where Mr. Eaton made his first experiments and where the new ovens have been in operation for several years, the partition walls were about $6\frac{1}{2}$ inches thick. At the Briton Ferry Iron Works in South Wales, where it was decided to adopt this plan of ovens from the success of those at Woodside when they had been at work only a few weeks, the partition walls were built only half a brick or $4\frac{1}{2}$ inches thick, and the results were more satisfactory than any that Mr. Eaton had obtained in France. This was to be attributed solely to the diminished thickness of the partition walls, and led the writer to test the point practically in the first block of ovens erected at Tursdale. In order to make a fair comparison, six ovens of the block were built with $4\frac{1}{2}$ inch partition walls, and six with 9 inch walls. The result was that in the same time $12\frac{1}{2}$ per cent. more coal could be coked in the ovens separated by only $4\frac{1}{2}$ inch walls than in those with 9 inch walls. The thickness of $4\frac{1}{2}$ inches is as little as can be safely used for the partition walls, and it was at first feared they might prove a little weak, being $8\frac{1}{2}$ feet long with an average height of $4\frac{1}{2}$ feet; but bound as they are on all edges they have proved to be thoroughly substantial, and it is intended to adopt this thickness in future. It has already been adopted with perfect safety in the two instances above mentioned at Briton Ferry and at Tursdale.

The economy secured in the new plan of oven arises from the circumstance that the heat requisite to start and urge the oven forward is supplied chiefly by radiation from the partition walls; and in a few cases only, owing to peculiarity of coal, is it at all necessary to assist the progress of the oven by the admission of air. The

principle of the oven aimed at is the entire exclusion of air, in order to prevent entirely the waste that takes place by partial combustion of the coke in the ordinary process; and this object is attained with certain rich gaseous and bituminous coals. But when dealing with intractable material, air is still needed: from 2 to 3 square inches of air space given beneath the door are amply sufficient to meet the case of the mixture of 45 per cent. of Staffordshire slack and 55 per cent. of Welsh bituminous slack. Whatever air is given to any oven, it is of the greatest importance to introduce it at the commencement of the coking process and not at the end. When introduced during the first period of the operation, its effect is to mix with and burn the gases which are being disengaged in great abundance from the coals, doing the coke very little injury: whilst its introduction towards the end of the operation is productive of serious mischief, for when the gases are beginning to clear off the air is free to attack the surface of the coke, and does so. To this fact there is a remarkable and curious exception in the case of the manufacture of coke from a mixture of Staffordshire slack and pitch, which seems to be accounted for by the formation of a silicious film or crust over the entire surface of the coke, which most effectually shields it from the action of the air. In all cases however, after the gases have ceased to be evolved in quantity sufficient to fill the oven, the further admission of air is prejudicial to the finishing off of the charge, by cooling down both the coke and the oven which contains it. At this period of the operation therefore, as is found the case in the first block of ovens erected at Woodside, it is necessary entirely to exclude the ingress of air, in order to prevent the rapid loss of heat which the oven otherwise sustains. When the air is thus excluded the oven has acquired a sufficient heat to complete the expulsion of all the gases that remain to be evolved, which are seen to issue burning as small jets of flame from the cracks in the mass of the coke. The regulator B, Fig. 4, Plate 22, allows the admission of air beyond the oven through the perforated cast iron plate which covers it, forming a perfect smoke consumer.

The area of the flue opening from the regulator into the chimney is a matter of considerable importance, and admits of an efficient adjustment by simply inserting pieces of firebrick in the passage of the

flue. This is a particular convenience where from any exceptional cause the admission of a considerable quantity of air is needed, as already referred to in the case of the first block of ovens erected at Woodside. Here the simple reduction of the area of the flue from 49 to 30 square inches at its passage out of the regulator occasioned an increased yield of 5 to 6 per cent. of coke. For with the flue full open, the draught of the chimney drew in more air than was required when the greater part of the gas had been driven off, and a surface combustion of the coke ensued with an intense heat, while the yield was sacrificed. It was found impossible to adjust the supply of air so nicely as to prevent waste while the coking proceeded, except by means of reducing the area of the flue, which proved quite efficient. Since in all classes of ovens perfectly air-tight work can scarcely be secured, the regulation of the area of the flue is a matter of importance even where the air is purposely excluded during the coking, in order to prevent its being drawn into the oven through the innumerable small interstices in the brickwork. The prevention of the undue admission of air by this simple expedient was attended with a diminution of the quantity of coal which could be coked in the same time; but this was counterbalanced by the increased yield of coke from the smaller quantity of coal charged. It may be that the checking of the draught has a beneficial influence by causing the gases to lie back a little longer in the oven and there expend a little more of their heat by being more completely consumed. On the other hand it is possible to reduce the flue area too much: for when it was attempted to work with the flue reduced at the passage from the regulator from 43 to about 23 square inches area, the effect ceased to be of any benefit, and on the contrary was slightly injurious in retarding the rapidity of coking and perceptibly lowering the temperature of the oven.

When the coking is completed, the communication between the oven and the chimney is cut off by a damper, consisting of a plain wrought iron plate, which prevents air from being drawn in through the brickwork whilst the coke is lying as it should do from two to four hours after disengagement of gas has to all appearance ceased. The fact is however that a slight disengagement is still though imperceptibly going on, which is made manifest by opening the door of the

oven, when immediately the gas is seen burning at the surface of the coke. It thus gives an improved appearance to the coke to let it lie a little, by getting rid of a tinge of dark colour which exists at the bottom of the coke if drawn too soon after being done.

As regards the general size of the new ovens, it is thought at present that 44 feet external diameter will prove the most convenient, as shown in Figs. 1 and 2, Plate 20; though at the Tursdale Colliery the first and second blocks are constructed 48 feet diameter. The objection to the large size is the necessity of providing for a greatly increased expansion of the structure.

As regards the quantity of coke which can be produced from a block of ovens, the second block at Woodside, 44 feet diameter, has turned out about 60 tons of coke per week during the two months that it has been in work. The first block at Woodside, 42 feet diameter, has scarcely turned out 55 tons per week, for the reason already given of too great thickness of the partition walls: whilst the first block at Tursdale, 48 feet diameter, where half the walls are 4½ inches thick and half 9 inches, is capable of turning out 80 tons per week. The block of ovens at Briton Ferry, 44 feet diameter with 4½ inch partition walls, is turning out from 65 to 70 tons of coke per week; and so satisfied are the proprietors that a second block has been erected.

As regards the time occupied in coking, an ordinary oven of 11 feet inside diameter with 95 square feet of floor area will burn off a charge of 5½ to 6 tons of Newcastle or Durham coals in 72 hours. One of the new ovens with 97 square feet of floor area, in the first block at Tursdale, 48 feet diameter, with 9 inch partition walls, burns off 4¼ tons in 72 hours with only a trifling difference in the gross amount of coke produced. But no account is here taken of the irregularities to which ordinary ovens are subject, and of which some idea may be formed from an incident that took place with the first block of the new ovens at Tursdale. Red bricks having succeeded perfectly in the chimney at Woodside were employed without hesitation in that at Tursdale; but owing to the increased size of the block of ovens, 48 feet diameter instead of 42 feet, and the more intense character of the combustion of the bituminous coals as

compared with the mixture of Staffordshire and Welsh slack, the heat was too great and caused the red brickwork to melt, and ended by closing up every flue. The chimney was then lined with firebricks: but during the time occupied in lining it, the ovens, which were then working in effect as ordinary open-topped ovens, worked most irregularly, never came up to their proper time, and in one instance a three days' charge occupied six days to burn off. It is not meant that ordinary ovens would be frequently subject to such an extreme irregularity as that just mentioned: for in the absence of the central chimney an oven of the new form is ill calculated to create a sufficient draught; whereas in an ordinary dome oven with chimney at top everything is pretty favourable for the admission of the requisite air. Irregularities of one or even two days in ordinary ovens are however of not unfrequent occurrence; and coupled with the accident which led to the necessity of working the new ovens at Tursdale Colliery without the assistance of the central chimney, they show of how great importance the chimney is to secure good and reliable results.

The cost of erection of a block of ovens on the new construction has been as follows at the Woodside Iron Works, the block being 44 feet diameter:—

35,000 Firebricks and clay . . .	112	0	0
27,000 Red bricks and mortar . .	33	0	0
Cast and wrought ironwork . . .	91	10	0
Tools	8	10	0
Labour in excavation, bricklaying, and concrete, &c.	70	0	0
	£315	0	0

This gives £26 5*s.* as the cost per oven, complete with water fittings, coke benches and tools, but exclusive of any attendant conveniences for keeping the coke in stock. The cost is of course subject to the addition of carriage of materials for erection at any other site, and minor modifications for the variation of circumstances. Where a mixture of coal is not wanted, the ovens can be made with a circular railway so as to be filled from the top, as at Tursdale, the additional expense of which is about £6 per oven.

The cost of working the new ovens where a uniform quality of coal is used is slightly in excess of the working of ordinary ovens in one particular only, that of loading up the coke from the benches into the wagons. In a straight row of ovens nothing is simpler than to run a train of wagons alongside the benches, off which the coke is conveniently filled at one lift. Against this there is the advantage that the labour of cleansing and charging the coal in the case of the new ovens is divided over a larger quantity of coke produced from the same quantity of coal; so that really the difference if any is but slight. The working cost per ton of coke made has been as follows, in the ovens already at work at Tursdale, 48 feet diameter:—

2 men drawing ovens, levelling coals, manufacturing, and keeping coke benches clean, at 3*s.* each per day, (coke made per day 12 tons) .	6*d.* per ton.
2 boys cleansing coals and charging with tubs, at 2*s.* 8*d.* each per day to feed 3 blocks of ovens . . .	1¾
Wheeling and loading coke into wagons	2¾
Interest on outlay, say £450 to cover incidentals, at 5 per cent. . .	1¼
Redemption in say 7 years . .	3½
Wear and tear say	¾
Royalty	3
Total cost of coke exclusive of coals .	1*s.* 7*d.* per ton.

In Staffordshire, with the admixture of slack and the charging done at the mouth of the oven instead of from the top, as might be expected the labour is somewhat greater, while the outlay is about £75 less per block. The cost per ton of coke made in this case is as follows:—

4 men drawing and charging ovens, mixing slack, &c., at 3*s.* 4*d.* each per day, (coke made per day 9 tons)	1*s.* 6*d.* per ton.
Interest on outlay, say £375, at 5 per cent.	1¼
Redemption in say 7 years . .	4
Wear and tear say	¾
Royalty	3
Total cost of coke exclusive of slack, &c.	2*s.* 3*d.* per ton.

To the above particulars of cost it is simply necessary to add that of material to arrive at the total cost of the coke manufactured. Taking the value of a North country bituminous slack at 3*s.* 6*d.* per ton, and a yield of 68 per cent. of coke, the cost of coals would be 5*s.* 2*d.* per ton of coke produced. Adding this to 1*s.* 7*d.* the cost of working, the total cost of the coke into wagons would be 6*s.* 9*d.* per ton. It is of course impossible to fix on any uniform price at which to charge the slack; some collieries produce "duff," as the small of the coal is called, in such abundance as to make them glad to have a means of getting rid of it; others set a higher value upon it. Hence it is for each in his particular circumstances to determine how far the adoption of the new system is economical.

It is easier to arrive at the real cost of the coke manufactured in the Staffordshire district, where slack suitable for the purpose can be bought in any quantity at 2*s.* 6*d.* per ton. Assuming this price, the mixture of 45 per cent. of Staffordshire slack at 2*s.* 6*d.* per ton with 55 per cent. of Welsh slack at 12*s.* per ton will cost 7*s.* 9*d.* per ton: and a yield of 57½ per cent. makes the cost of the coke 13*s.* 6*d.* per ton. Adding this to 2*s.* 3*d.* the cost of working, the total cost of the coke amounts to 15*s.* 9*d.* per ton.

The mixture of 44 per cent. of Staffordshire slack at 2*s.* 6*d.* per ton with 44 per cent. of Welsh slack at 12*s.* per ton and 12 per cent. of pitch at 20*s.* per ton costs 8*s.* 9*d.* per ton; which with a yield of 62½ per cent. makes the coke cost 14*s.* per ton. Adding this to 2*s.* 3*d.* the cost of working, the total cost of the coke from this mixture amounts to 16*s.* 3*d.* per ton.

The mixture of 72½ per cent. of Staffordshire slack at 2*s.* 6*d.* per ton with 27½ per cent. of pitch at 20*s.* per ton costs 7*s.* 4*d.* per ton; but the yield in this case is only about 52½ per cent. of coke, owing to the very volatile character of the pitch, and the coke therefore costs 14*s.* per ton. Adding this to 2*s.* 3*d.* the cost of working, the total cost of the coke made from Staffordshire slack with pitch alone amounts to 16*s.* 3*d.* per ton.

As regards the wear and tear of the brickwork of the new ovens, there seems every likelihood that this is very small and unimportant.

A small allowance has however been made in each of the above estimates of the working cost. The first block of ovens erected at Woodside has been in operation since June last year, a period of nearly a year, and does not show the slightest indication of requiring repairs to the brickwork. A little repair has been needed at the door frame castings, owing to the irregular expansion of the casting by heat and its weak form; but the liability to fracture in the faulty plan first adopted has been in a great measure corrected by an amended form of frame.

Among the advantages which attach to the new form of oven is its compactness, which is of importance and is a reason why the oven should be much cheaper in its construction than ordinary round ovens. Taking the case of a double row of ordinary ovens placed back to back, 11 feet internal diameter, the floor area of which would be 95 square feet, with a flue between them common to both leading to a chimney, such a series of 6 ovens in length or 12 ovens in the double row would cover a space of ground $84 \times 28 = 2352$ square feet; whereas the space covered by the largest block of the new ovens yet erected, 48 feet external diameter, is only 1810 square feet, while the floor area of each oven is 100 square feet, the partition walls in this case being $5\frac{1}{2}$ inches thick. Including the coke benches 9 feet wide in the case of the double row of ordinary ovens, the ground occupied would be $84 \times 46 = 3864$ square feet: whilst in the case of the 48 feet block of the new ovens a greater area of ground is covered, taking a square larger by 18 feet than the diameter of the oven, giving $66 \times 66 = 4356$ square feet; with the advantage however of larger stacking room for the coke, for whilst the bench room in the first case cited of 12 ovens in a double row is $84 \times 18 = 1512$ square feet, that of the 48 feet block is 2546 square feet.

In connexion with the subject of rapid coking, a few interesting laboratory experiments have been made at the writer's works. The material operated upon was the coal from the Tursdale Colliery, the composition of which was as follows:—

Carbon	81·46
Hydrogen	7·89
Nitrogen	2·91
Sulphur	1·34
Ash	3·26
Difference (oxygen)	3·14
	100·00

The yield of coke which any coal is capable of producing depends in a certain measure upon its constituents. In general the gaseous products cannot be expelled without carrying off with them a certain proportion of carbon. Could all the hydrogen, nitrogen, sulphur, and oxygen be expelled without carbon, the coal of which the above is an analysis should yield nearly 85 per cent. of coke: but the highest result obtained in the laboratory was only 69½ per cent. The yield of coke however is dependent also to a certain extent upon the rapidity with which the coal is raised to the coking temperature, as the following five experiments will show.

In the first experiment two crucibles carefully covered, containing Tursdale coal, were introduced into a close muffle, so that access of air to the contents of the crucible was rendered impossible. The muffle was at a very bright red heat, and the crucible having been put into it the mouth of the muffle was temporarily stopped. In one hour afterwards the crucible was removed, and the percentage of coke in one crucible was 62·18 and in the other 61·28.

In the second experiment a crucible was introduced into the muffle when cold, and the temperature gradually raised during one hour to cherry red, and then maintained for half an hour at a bright red heat. The yield in this case was 66·12 per cent. of coke.

In the third experiment two crucibles were introduced into the muffle when at a bright red heat, but not so hot as in the first experiment, and the temperature was maintained for an hour. One crucible gave 64·77 per cent of coke and the other 64·20 per cent.

In the fourth experiment a crucible as in the second experiment was introduced into the cold muffle, and the temperature raised in an hour and a half to cherry red, instead of occupying only one hour as in the former case. The resulting yield was 67·50 per cent. of coke.

In the fifth experiment a crucible introduced into the muffle at a dull cherry red heat and kept at that temperature for one hour yielded 69·40 per cent. of coke. A second crucible raised in one hour to a dull cherry red heat and kept at that heat for one hour, also yielded 69·40 per cent. of coke.

It appears from these experiments that the more rapidly the coal is coked or the higher the temperature of the oven into which it is introduced, the less the yield; and this is no doubt due to the greater readiness with which compounds of carbon and hydrogen containing an increasing proportion of carbon are formed, the more sudden or the greater the intensity of heat. On the other hand it was noticed in the above experiments that the coke more slowly made was more bulky, that is less dense, than that made more rapidly. This result fully accords with that obtained in some flued ovens in the north, the invention of Messrs. Breckon and Dixon; the coke produced by the flued ovens being much denser in character than that made in ordinary ovens. How far yield is interfered with by the use of flues is a question which admits of further enquiry; and at some future time the writer may be in a position to make a comparison between Tursdale coke produced in flued and non-flued ovens in order to determine this point. Taking an average however of several specimens of coke produced in ordinary ovens from North country coal, the specific gravity is only 1·00, whilst the specific gravity of Tursdale coke made in the new ovens is 1·47. However much therefore this high specific gravity of the coke may be due to some favourable peculiarity of the coal, it is evident that in the new mode of coking both yield and density are secured. There is a further objection to coking from the bottom of an oven upwards, as in ovens having flues underneath the floor, from the fact that the two processes meet in an irregular plane about one third of the way up from the floor of the oven, and there result two measures, so to speak, of coke. This is perhaps a trivial objection, inasmuch as it interferes only with the commercial appearance of the coke and no real detriment to its quality; still it is one which is obviated in the new ovens.

The Chairman exhibited specimens of the coke made in the ovens, illustrating the respective binding properties of the different mixtures of slack employed. He observed that the main object of the plan of coking now described was to effect economy of material in ironworks by making use of the great quantity of fine slack that was at present thrown away as waste; which was of particular importance in the South Staffordshire district, where they were gradually getting short of material by the rapid consumption of the Thick coal within the limits at present worked. Attempts had previously been made to coke the fine slack by itself, but had quite failed; and he had then tried it mixed with Welsh bituminous slack, to impart the requisite binding property, and with pitch. By this means the refuse ordinarily thrown away was converted into a coke even superior to the best coke made from the large Thick coal, the proportion of pitch mixed with the slack being about $27\frac{1}{2}$ per cent. of pitch to $72\frac{1}{2}$ of slack. The coke obtained had all the excellent qualities of the Thick coal coke, and the same freedom from injurious ingredients, since the pitch imparted no noxious elements. In bringing the subject forward for discussion his object was to show the practicability of the plan by the results already obtained; and also to ascertain how far the same process was capable of being extended to other non-caking coals, and whether the new form of ovens was suitable for other districts, as had already been found to be the case in the trial of the ovens at Tursdale with North country coals and at Briton Ferry with South Wales small coals. He was indebted to his son for carrying out the several experiments that had been made with different mixtures of slack.

Mr. W. Haden quite agreed with the importance of the subject; for if they were enabled to make a really good and regular coke from the waste slack of South Staffordshire it would be a great gain to the district. He enquired what was the effect of using a smaller proportion of pitch with the slack.

The Chairman said, with a smaller proportion of pitch the mixture was not sufficiently binding, so that the coke produced would not hold together, but came out of the oven all in small pieces.

Mr. N. N. Solly enquired whether any trial had been made of New Mine slack for coking; and whether the Thick coal slack had been tried by itself since the new ovens were got to work.

The CHAIRMAN had not yet tried New Mine slack, and the Thick coal slack would not bind at all by itself.

Mr. N. N. SOLLY asked whether the flues from the ovens to the chimney had ever got choked up with any accumulation of dust, in consequence of using entirely the fine slack for coking.

The CHAIRMAN said there was not the least accumulation in the flues, the draught on the ovens being so strong as to carry off any fine particles of slack.

Mr. SAMUEL LLOYD suggested that a saving might be made by placing a vertical boiler in the centre of the block of ovens, where the chimney at present stood, so as to economise the heat passing off from the ovens. He thought the heat would be found considerable from so many ovens, as four moderate sized coke ovens at their works at Wednesbury gave heat enough to raise the steam of a boiler 28 feet long and 8 feet diameter. The chimney might be placed in any convenient position near, with an underground flue to it from the ovens.

The CHAIRMAN replied that in this instance the boilers were too far off from the ovens to make that practicable; and it would be a question whether it was really advisable to encumber the ovens with a boiler, as there did not appear to be gas enough escaping from the chimney to be worth the trouble of saving.

Mr. E. A. COWPER asked what sort of coke was made in the ovens referred to at Wednesbury, whether as large and dense as that shown from the new ovens; for if there were gas constantly burning out of the chimney there must be a waste of material in the oven and a smaller yield of coke.

Mr. S. LLOYD replied that the coke made at those ovens was only a light soft coke.

The CHAIRMAN remarked that the new ovens had an important advantage in the greatly increased density of the coke produced, which had a great deal to do with its quality as fuel and its value in the blast furnace: with the mixture of fine slack and pitch, the specific gravity of the coke produced was as much as 1·25 or 1·30; and the Tursdale coke made in the new ovens had a specific gravity of 1·47, while that of the best North country coke scarcely reached 1·00 in

the regular make. This showed clearly the importance of preventing the waste of so much valuable material out of the coke, which at present took place with ordinary ovens. The specific gravity was ascertained by weighing the coke solid in air and in water.

Mr. J. E. Swindell asked what was the value in the blast furnace of the coke made by the new method, as compared with the best North of England coke.

The Chairman replied that there was no question as to the superiority of the Staffordshire slack; it made a better and purer coke than the North country coals, whether coked with pitch alone or with a mixture of Welsh slack and pitch. With Durham coke they were not able to make a good open-faced grey forge pig, but with this coke good grey pig was regularly made. It also gave a better yield in the furnace than either the Durham coke or that made from the Thick coal.

Mr. S. Lloyd supposed the coke would be more free from sulphur than the North country cokes.

The Chairman said that was the case, the slack being like the Thick coal itself for purity of quality.

Mr. E. A. Cowper asked whether any means were taken to rid the slack of iron pyrites by having it picked before being put into the ovens.

The Chairman replied that the slack was not picked or cleaned in any way before coking, but was put in the ovens just as it was thrown over the bank; the fine slack that he was using was the refuse left after the coarse slack had been screened for making what was called breeze to be used under boilers and for other purposes. In this way 60 tons of good coke per week were now being produced from refuse coal slack previously of no value whatever.

Mr. W. Haden had no doubt many colliery owners would be glad to supply any quantity of the refuse slack for coking, merely for the sake of getting rid of it out of the way.

Mr. J. Murphy enquired whether the mixture of Welsh slack or pitch alone produced the cheapest coke.

Mr. C. Cochrane replied that the coke made with pitch alone was decidedly the cheapest at their works at Dudley, about 1*s.* per ton

cheaper than with Welsh slack, on account of the price of the Welsh slack and the cost of conveyance from such a distance. The cost of the two modes of coking in any locality depended of course on the relative cost of the materials for mixing; and the estimated cost given in the paper was of a general character, based upon the full market value of the pitch and Staffordshire slack, which however had been obtained at a lower rate in this particular instance at their works at Dudley.

Mr. J. Murphy enquired which coke was best for ironmaking.

Mr. C. Cochrane replied that the mixture with pitch alone gave the coke that made the best iron; with this coke grey forge pig iron could be produced with great facility, as the sulphur contained in the coke was not more than 0·8 per cent., whilst that quality of iron could not be made with Durham cokes at all.

Mr. J. Paddon observed that the economy and advantage of any mode of coking would vary much in different localities, according to the quality and cost of materials in the district. In Staffordshire it was a great object to economise the waste slack now thrown away as useless; and the plan of coking just described converted into a valuable fuel what was otherwise worthless. In some parts of South Wales also there was material which had never before been converted into coke, such as the Aberdare slack and other small coals, and this was now coked in the new ovens by mixing with it a portion of bituminous slack. In other parts of South Wales however the case was not the same, the cost of slack being not more than 2*s.* or 3*s.* per ton less than that of the whole coal: where the slack was bituminous it made good coke by itself without any mixture, and anthracite slack was mixed with half as much of the bituminous slack, producing one of the best blast-furnace cokes in South Wales, which cost only 8*s.* 6*d.* or 9*s.* per ton.

The value of the new ovens he thought had been rather understated in the paper than the contrary, the coke having been weighed dry immediately on being drawn; but if stacked and left exposed to the atmosphere for some time, as was usually the case, it absorbed a considerable proportion of moisture which increased the apparent weight; and in estimating the commercial value of the coke as

compared with that made in the ordinary ovens, both should be weighed under the same conditions. Even without this precaution however the new ovens appeared decidedly superior in yield; he was satisfied they would yield in regular work as much as 70 to 75 per cent. of the coal used, and he knew of one instance in which the yield reached 78 per cent., when the coke would have weighed still more if it had been left stacked after drawing. As regarded the duty of the coke in the blast furnace, he had seen the new ovens working at the Briton Ferry Iron Works, and was informed by the furnace manager that the coke from the new ovens did fully 7 per cent. more duty and was a finer coke than any made from the same coal in ordinary ovens.

The new ovens had therefore a superiority not only in the greater yield and density of the coke produced, but also in giving the means of making a commercially valuable coke from a material never before successfully employed for any useful purpose; and he was sure the economical using up of the vast quantities of waste slack at present thrown away was a most important problem for the future prosperity of the South Staffordshire district.

Mr. J. Anderson moved a vote of thanks to the Chairman for his very interesting and valuable paper, which was passed.

The following paper, communicated through Mr. Walter May of Birmingham, was then read :—

ON A BOILER, ENGINE, AND SURFACE CONDENSER, FOR VERY HIGH PRESSURE STEAM WITH GREAT EXPANSION.

By ALEXANDER W. WILLIAMSON, Ph. D., and Mr. LOFTUS PERKINS, of London.

The Boiler, Engine, and Surface Condenser, forming the subject of the present paper, have been designed, constructed, and worked by the authors with a view to promoting the adoption of very high pressure steam with great expansion: the engine is of 60 horse power and works at a pressure of 500 lbs. per square inch, as it was thought desirable to adopt at once appliances suited for considerably higher pressures than those proposed for general use. Although however it has been endeavoured to make a boiler which would be safe at any attainable steam pressure, it is not considered necessary by the authors for the present requirements of steam engines to use pressures above 140 to 160 lbs. per square inch: and the practical object of the present paper is to give substantial grounds for confidence in working at such moderate pressures; and to show how, with steam at these moderate pressures, engines free from the most serious drawbacks of ordinary expansive engines can be made to work with a consumption of 1 to $1\frac{1}{4}$ lbs. of coal per horse power per hour. As the use of impure fresh water or of salt water is attended with a variety of inconveniences and disadvantages, which are more serious the higher the pressure that the boiler is worked at, it appears indispensable to use a surface condenser for an engine working at high pressure; so as to condense in a pure state all the steam that goes out of the boiler, and supply nothing but distilled water by the feed pump: and several important incidental advantages are gained by this plan.

The Boiler, shown in Figs. 1 and 2, Plate 23, consists of a number of horizontal straight wrought iron tubes A, welded up at the ends, and connected with one another by smaller vertical pipes B, as shown enlarged to one quarter full size in Fig. 6, Plate 25. These tubes contain the water to be evaporated, and the steam, whilst the fire is outside them. It is essential that the larger tubes be horizontal or nearly so, and that each of them be connected to the next tube by means of two of the connecting pipes. The boiler contains five layers of the larger tubes of $2\frac{1}{4}$ inches internal diameter and 3 inches external; the connecting pipes are $\frac{7}{8}$ inch internal diameter and $1\frac{3}{8}$ inch external. In working, the water level is in the middle layer of tubes, as shown by the dotted line in Figs. 1 and 2; it remains free from the violent undulations which occur frequently in boilers where the internal space is not divided off. It is probable that a circulation establishes itself in the water, which rises with the bubbles of steam through the vertical connecting pipe at one end of the tube and descends by itself through that at the other. The hot gases from the fire pass backwards and forwards between the layers of tubes, as shown by the arrows in Fig. 2, and remain long enough in contact with them to allow of a very good absorption of the heat. In another similar boiler used for some time there were eight layers of tubes above the fire. The boiler is thus made up of a number of vertical subdivisions arranged side by side, each containing five to eight parallel tubes. The several sections are all connected together at the bottom by means of a cross tube C with connecting pipes to each section, through which the water finds the same level in all the sections. The steam is taken off through a similar cross tube D at the top of the boiler, with a connecting pipe to the highest tube of each section. All the sections are proved with water pressure up to 3000 lbs. per square inch.

The boiler has about 12 square feet of grate surface, but the total area of the air spaces between the bars does not amount to more than is supplied by 6 square feet of ordinary grate surface; and accordingly the fire is large but slack. The total heating surface amounts to 882 square feet. The capacity is about 40 cubic feet, half of which is water space and half steam room. The whole boiler is firmly held together by cast iron girders, and encased in non-conducting sides and

top made of four thicknesses of light plate riveted together and kept about $\frac{3}{4}$ inch apart by ferrules, so as to form three closed air chambers. This arrangement is specially adapted for marine boilers.

The flue from the boiler is made to pass through a box E, Figs. 3 and 4, Plate 24, containing the three cylinders of the engine, passing first down the small or high pressure cylinder F, then up the middle one G, and finally acting on the low pressure cylinder H. The temperature of the gases in this box varies from 400° to 500° Fahr. After leaving the box they pass downwards through a vertical square flue 10 feet long, giving up their remaining heat to the feed water which is forced up through a wrought iron coil of $\frac{7}{8}$ inch pipe contained in the flue, having 200 square feet of heating surface. At the bottom of this flue the gases enter a vertical iron funnel of 40 feet height and 24 inches diameter. The heat is so completely abstracted by the feed-water coil, that after leaving it the gases have never been found hotter than 100° Fahr.

This small quantity of heat in the chimney gave sufficient draught to cause the evaporation of $8\frac{1}{2}$ cubic feet of water per hour in the boiler; but by the aid of a small fan, driven by a belt from the main shaft of the engine, the evaporation was usually kept at 15 cubic feet per hour. The evaporating power of the boiler was tested by means of a water meter, and in an experiment of 5 hours' duration 390 lbs. of anthracite coal evaporated 420 gallons of water, which is about $10\frac{3}{4}$ lbs. of water per lb. of coal. There is no doubt that a larger boiler with smaller proportionate loss of heat by radiation to the outer air would give a still more favourable result.

The great strength of this construction of boiler is the result of its being in reality an aggregate of a number of very small boilers. It absorbs the heat from the flue with the facility of a moderate thickness of iron, $\frac{3}{8}$ inch, without ever having a calcareous lining to keep the water away from the hot metal; while at high pressures it is exposed to less strain than ordinary boilers at comparatively low pressures. Thus the shell of a cylindrical boiler of 5 feet diameter, or 26 times the internal diameter of these tubes, will be exposed to 26 times as great a strain as the sides of the tubes when containing steam of the same pressure; or at 19 lbs. pressure it will have as

great a strain as the tubes at 500 lbs. But even if tubular boilers were made so thin as to be equally liable to give way with large boilers, they would still be much safer to use; for if one of the tubes were to be destroyed, the water from the neighbouring tubes would be driven out through the small connecting pipes, by which it is in communication with the rest of the boiler, in a very quiet sort of way compared with that in which the contents of a large boiler are thrown out when one of its ends gives way or its shell is rent open. In fact explosions in the ordinary sense of the word are impossible with these tubular boilers. It is well known that tubes are more effective and safe when containing the water and steam within them than when containing the hot gases from the furnace and exposed to an external pressure of the surrounding steam, since the tenacity of wrought iron is greater than its stiffness. The tubular boilers also admit of being easily and speedily repaired, by taking out a defective section and replacing it by a fresh section or by new tubes kept in store for such contingencies. So little space is taken up by the tubes of these boilers that more space can be afforded for the flues and firegrate surface than usual; and the whole space occupied is only about half that taken up by plate boilers of equal mechanical power.

The Engine, shown in Figs. 3 and 4, Plate 24, is of 60 horse power and works at a pressure of 500 lbs. per square inch. It consists of three single-acting cylinders of 12 inches stroke, all attached to a single crosshead I with a connecting rod at each end to the crank shaft K. The steam passes through the three cylinders successively, the down stroke being made by the simultaneous action of the first and third cylinders F and H, and the up stroke by the action of the middle cylinder G alone; so that the three attached to the same crosshead act as regards the rotation of the shaft like one cylinder.

The diagram Fig. 7, Plate 25, is a vertical section of the three cylinders to a larger scale, showing the position of the valves during the up stroke. The steam after having expanded in the down stroke above the piston of the first cylinder F of 6 inches diameter is allowed by the lifting of the conical valve M to pass under the piston of the

second cylinder G of 15 inches diameter, and at the same time under the piston of the first; so that during the up stroke or working stroke of the second piston, the piston of the first cylinder is in equilibrium, and the steam is expanding into the second cylinder of 6 times the area. The valve M between these cylinders then closes, leaving open the passage between the bottoms of both, while the first cylinder F is receiving a fresh supply of steam from the boiler through the steam valve L. At the same time the valve N between the second and third cylinders G and H is lifted and the steam allowed to pass above the pistons of both these cylinders, leaving the second piston in equilibrium and driving the third piston down. In the down stroke therefore there is the same pressure of steam in the top of the third cylinder H, in both ends of the second cylinder G, and in the bottom of the first cylinder F. The bottom of the third cylinder is constantly in communication with the vacuum of the condenser. The third cylinder is of the same diameter as the second, so that at the end of the down stroke the steam has expanded to about 12 times the volume of the first cylinder. When the down stroke is completed, the conical exhaust valve O allows the steam from the top of the third cylinder and also from the top of the second to escape into the surface condenser P, Fig. 3, Plate 24; whilst the valve N between the second and third cylinders falls to its seat, closing the passage between the bottom of the second and the tops of both. The whole effect therefore of this arrangement, which works with great simplicity, is that in the up stroke the first and third pistons are in equilibrium and the second piston has the vacuum on the top of it; and in the down stroke the second piston is in equilibrium and the first piston works against a back pressure equal to the pressure of the steam on the top of the third piston.

The indicator diagrams from the three cylinders are shown in Figs. 8 and 9, Plate 26. That from the first cylinder, Fig. 8, was taken from the passage between the first and second cylinders at the point R, Fig. 7, since there was not room for fixing the indicator on the small cover of the first cylinder. The cylinders being all single-acting, with the pistons in equilibrium during the return stroke, the exhaust line in each diagram represents the back pressure on the

opposite side of the piston during the working stroke: so that each diagram represents completely the effective pressure in each cylinder, as in diagrams taken from ordinary double-acting cylinders. In Fig. 8 the back pressure on the bottom of the first piston during the down stroke is the same as the working pressure on the top of the third, as already explained, while the bottom of the third cylinder is open to the condenser; and in Fig. 9 the up stroke of the second cylinder is made against the vacuum of the condenser.

When the steam in the first cylinder is allowed to expand to 4 times its original volume during the down stroke, it has expanded to 7 times as much or 28 times its original volume by the end of the up stroke of the second cylinder; and hence a considerable fall of temperature necessarily takes place in the steam, with a consequent abstraction of heat from the inside of the first cylinder, and also from the bottom of the second, which is still further cooled by the expansion of the steam in the third cylinder to 48 times its original volume. Not only are the two last cylinders cooled by contact with steam which has lost heat by great expansion and is reduced to a temperature considerably lower than that at which it entered the first cylinder; but still more by the evaporation at low pressures of the water deposited at the beginning of the stroke by the condensation of steam upon the cooled sides of the cylinders. That water is contained in the bottom of the second cylinder was proved by inserting a screw cock at the lowest part of the passage between the second and third cylinders; and another proof is given by the remarkable fact that the quantity of steam calculated from the end of the indicator diagram of each successive cylinder is $6\frac{3}{4}$ cubic feet from the first, $9\frac{1}{2}$ cubic feet from the second, and nearly 14 cubic feet from the third, showing that steam is condensed at the beginning of the stroke of the first and second cylinders, and subsequently evaporates into the next cylinder. The first and second cylinders together condense about half the steam, a proportion which probably does not exceed the condensation of many condensing engines of far less expansion; yet on account of the higher initial pressure of steam the consumption of coal per horse power is only about $1\frac{1}{2}$ lbs. per hour.

The engine was made to run fast in order to allow little time for evaporation of internal moisture in the cylinders between the strokes; and in all respects gives the most favourable trial to the principle of great expansion from a high pressure through a succession of cylinders communicating directly with each other. In order to preserve from injury the cotton packing of the rod that lifts the steam valve L, Fig. 7, of the first cylinder, which is exposed to steam of very high temperature, a horizontal cast iron tube about 18 inches long is fixed to the valve chest above the cylinder, containing a steel shaft with a cam on its inner end which lifts the valve. The shaft nearly fills the cast iron tube, and all escape of steam is prevented by a stuffing box packed with cotton at the outer end of the tube, which always remains cold since there is no passage of steam through the tube. This plan of lifting the valve is found perfectly effective and convenient.

For constructing larger engines to expand a greater number of times effectively, the arrangement that is most advantageous depends upon the initial pressure of steam. If steam is used at 500 lbs. initial pressure, it is thought best first to expand it down to about 125 lbs. pressure in a couple of single-acting cylinders, connected either on opposite cranks or at opposite ends of a lever, so as to be equivalent in their action to one double-acting cylinder. The valves would be conical valves lifted in the manner described above. From 125 lbs. the steam may then be expanded down further through a succession of double-acting cylinders with ordinary slide valves.

But for most purposes there is no doubt that sufficient economy of fuel can be attained by working at an initial pressure of 160 lbs., and by expanding the steam about 16 times, if it be done properly; and the appliances for this purpose are of the simplest kind, involving no novelty of construction but merely of arrangement. It is submitted that the mechanical and physical defects of all existing arrangements for getting more work than usual out of steam, by making it expand many times in one cylinder, may be avoided and their object more fully carried out by four common double-acting cylinders with simple slide valves. The cylinders would be of the same stroke, with areas

in the proportion of 1, 2, 4, and 8, connected to four cranks on the same shaft, and with moderate sized tubular steam chambers to dry and slightly superheat the steam between each cylinder. By making the first and second cylinders work on opposite cranks and close to each other, one would be pulling up while the other is pushing down, thus neutralising the friction on the main journals. The third and fourth cylinders would likewise work on opposite cranks, set at right angles to the first pair, so as to distribute the power with uniformity throughout the whole revolution, the steam being cut off in each cylinder at two-thirds of the stroke. Each cylinder communicates with the next by means of a steam chamber composed of drawn tubes connected together in the same manner as the tubes in the boiler already described, and placed in the flue from the boiler for the purpose of superheating the steam to maintain the initial temperature throughout the whole expansion. Each steam chamber supplies steam to the next cylinder during the first part of the stroke, until the slide valve cuts it off and allows the steam to expand during the remainder of the stroke; and in each stroke as much steam is supplied to the chamber from the preceding cylinder as goes out into the next cylinder. Thus the supply of steam to the second cylinder being cut off at two thirds of its stroke, which is also two thirds of the exhaust stroke of the first cylinder, the remaining steam in the first cylinder and the intervening chamber is compressed into the chamber during the remaining third of the stroke, its pressure being thereby raised to the original pressure in that chamber, so that the next and each succeeding stroke of the second cylinder commences with the same pressure of steam. A similar process is carried out in the remaining cylinders and steam chambers.

When steam in expanding through a succession of cylinders with intervening steam chambers leaves each cylinder at the same pressure as the steam in the chamber into which it passes, it necessarily gives theoretically the same gross work on the pistons as if it expanded to the same amount in a single cylinder. Practically however it is impossible to expand so much as 16 times in one cylinder without introducing many serious evils which bring down the power to a mere fraction of its theoretical amount; whereas the expansion of the steam to double

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its volume in one cylinder can be carried out without difficulty or inconvenience.

The degree to which the steam will be superheated in the intermediate steam chambers depends on the temperature of the flue in which they are placed; but as the tubular boiler exposes a large extent of heating surface to the action of the hot gases from the fire before they come in contact with the steam chambers, no inconvenient amount of superheating is likely to occur, nor any burning out of the chambers. It is desirable to arrange the superheaters so that the hot gases may come in contact with them in the same order in which the steam goes through them, so as to act last on the coolest steam chamber.

The Surface Condenser used with the engine previously described is shown in Fig. 3, Plate 24. It consists of a number of straight wrought iron tubes fixed vertically in a chamber P, closed at the upper ends and screwed by their open ends into a thick plate at the bottom, as shown enlarged to one quarter full size in Fig. 5, Plate 25. These tubes contain the cold water, which circulates rapidly through them, and their outer surfaces are exposed to the steam to be condensed. Each of the tubes contains a smaller tube open at both ends, and through this inner tube the condensing water is driven up by the pump S, Fig. 3, to the top of the outer tube, and then descends through the annular space between the tubes, as shown by the arrows in Fig. 5. The object of this arrangement is to prevent the possibility of any straining and consequent leakage of the tubes from heating or unequal expansion, by having all the tubes fixed at one end only, with the other end left free. The condenser in use has about 20 square feet of cooling surface for every cubic foot of water condensed per hour, and the vacuum obtained by it varies from $26\frac{1}{2}$ to $28\frac{1}{2}$ inches of mercury, notwithstanding that the air pump T, Fig. 4, is exceedingly small in proportion.

An incidental but not unimportant advantage of using a surface condenser is that it keeps the water level in the boiler constant without any trouble to the engineer, by always returning to the boiler the exact quantity of water that has been taken out as steam. For

circulating the water through the tubes of the condenser the arrangement best suited for marine engines is a lift pump or air pump to draw the sea water through them, with a screw cock on the inlet pipe by which the supply of water can at pleasure be throttled; so that even if a leakage were to arise in the tubes of the condenser, no sea water could get in to mix with the distilled water, but on the contrary an outward leakage would occur if care were taken to keep the vacuum inside the tubes a little better than that in the condenser. In order to supply the place of any distilled water that might escape by leakage or otherwise, a small still should be attached to the boiler, heated by means of a coil of steam pipe of which one end communicates with the steam room of the boiler whilst the other is over the hot well and is provided with a screw cock. As soon as this cock is allowed to drip or run, the still will begin to work and replenish the boiler with distilled water through the usual channel of the condenser.

Mr. E. A. Cowper observed that the advantages of high pressure steam were now generally acknowledged, and the pressure of steam in engines had been gradually raised, having risen now in locomotives from 100 lbs. to 150 and even 200 lbs. per square inch. He therefore thought it was desirable to look boldly at the advantages of a much higher pressure, as had been done in the paper just read, where it was proposed to work with 500 lbs. steam, and the engine described had been worked at that pressure to show the advantages practically. The boiler he had seen working at that pressure, and it certainly appeared a very strong construction. With a high pressure of steam he had long considered the use of a surface condenser and distilled water in the boiler essential to economy, and it was attended with advantages of great importance: the necessity for cleaning the boilers was done away with, as no deposit could ever be formed, and the water level was

maintained constant, whatever quantity of steam was taken off by the engine; while there was only 1-25th as much water to pump out of the condenser, and, what was of even greater importance, the pumping out of the air introduced with the injection water in ordinary condensers was saved.

Mr. Perkins said the indicator diagram shown from the first cylinder was taken from the passage between the valve and cylinder, because there was not room to get the indicator on the top of so small a cylinder. The boiler pressure was 570 lbs., and the spring of the indicator made the figure jump up to 600 lbs. when the steam was admitted, but the actual pressure was only 510 lbs. total at the time of cutting off. The steam was cut off at 1-4th of the stroke in the first cylinder and expanded down to 170 lbs. total pressure or about 3 times, when it was exhausted into the second cylinder, the pressure dropping to 88 lbs. total in the passage between the cylinders; from the second cylinder it was exhausted at 36 lbs., and dropped to 30 lbs. in the passage to the third cylinder, from which it was let out into the condenser at a pressure of 27 lbs. total, making the whole expansion from the commencement amount to about 19 times.

Mr. E. A. Cowper remarked that as the pipe from the cylinder to the indicator was long, there might be an accumulation of water in it which would cause the indicator to jump by its momentum. He enquired whether the drop in the pressure in exhausting from one cylinder into the next was owing to the passages between the cylinders being large.

Mr. Perkins replied that the passages were not large, but the drop was occasioned by the steam being cooled from want of sufficient heat in the casing to maintain the temperature. The pipe from the cylinder to the indicator had to be made long in order to keep the packing of the indicator from being burnt by the high temperature of the steam; consequently the pressure was probably somewhat lower in the indicator than in the cylinder.

Mr. W. Bouch enquired whether the indicator diagrams varied with the speed of running, and what was the speed when they were taken.

Mr. Perkins replied that there was a variation in the diagrams according to the speed of the engine, but they were not so reliable at a high speed, on account of the oscillation of the indicator, and the engine was therefore worked at only about 60 revolutions per minute whilst the diagrams were being taken and slower than would be the case in actual work, when it would run at about 100 revolutions per minute.

Mr. M. Smith enquired how long the engine had been at work, and what was its cost.

Mr. Perkins replied that the engine had not yet been applied to regular work, but had been working experimentally during the last six months with a friction break to test the practicability of the plan. The cost was about the same as that of marine engines, namely £50 to £60 per nominal horse power including the boiler, the engine indicating however from 2½ to 3 times the nominal horse power.

Mr. E. A. Cowper observed that the larger engine suggested in the paper with the steam expanded through four cylinders working in pairs on cranks at right angles would give a very uniform driving power, with probably only from 10 to 25 per cent. variation in driving power throughout the revolution, according to the point of cutting off in each cylinder.

Mr. W. Weild asked why the driving shaft was placed below the cylinder, for manufacturers generally objected to having the engine inverted, from the greater difficulty of keeping it in order and doing repairs.

Mr. Perkins said in the present engine they had only taken the common form used for propeller engines, but for manufacturing purposes the engine would be reversed in position, and it might be arranged in any way to suit convenience.

Mr. W. May had seen the engine at work when it was driving the friction break, and it appeared a useful step towards improved economy in steam engines, by showing the practicability of much greater pressure and expansion, whether the details of construction at present adopted were considered the best or not. The boiler seemed in good order and perfectly safe for the high pressure of steam; it could be easily repaired by the removal of any portion without interfering with

the rest of the boiler. The temperature in the chimney was remarkably low, the iron casing being so cool that the hand could be borne on it.

Mr. J. Cochrane enquired whether there would not be some difficulty with the boiler from the chance of the small connecting pipes getting choked up if the water were not perfectly pure.

Dr. Williamson said that in larger boilers larger connecting pipes would be used, and the smaller pipes were certainly liable to become incrusted with common water; but where pure water was used with a surface condenser, there was nothing that could ever get into the pipes to choke them, and it was not contemplated to work a boiler of this construction except with a surface condenser. The only way to ensure safety and durability in such a boiler or in any other kind of boiler was to avoid the evil of incrustation by using a surface condenser, without which he thought no boiler ought ever to be worked at high pressures. In the present boiler no incrustation had as yet been experienced nor could any take place, but the boiler would be spoiled directly if used with ordinary water and an injection condenser. The principle of surface condensers had been established by many previous trials, and various forms of construction had been devised. The gridiron condenser on Mr. Cowper's plan had been successfully employed, having the steam passed through a set of horizontal pipes with water continually trickling over them outside, whereby a vacuum of 29½ inches of mercury was obtained and kept up for a long time. This was a very effective form of surface-evaporative condenser, and the only objection to its use was that it was bulky and inconvenient on board ship, on which account he preferred something more like Hall's condenser; and in order to get over the difficulty of the tubes leaking at the ends in consequence of being loosened by alternate expansion and contraction, the tubes in the condenser now described were fixed only at one end and left free at the other, and therefore could not leak as there was no strain on the air-tight joints.

The present engine was intended simply as a practical instance of using very high pressure steam, and not as the most perfect mode of working the steam, but to show that working at 500 lbs. pressure was as easy as at ordinary moderate pressures. The pressure of steam

already in use in other engines had risen gradually to 200 lbs., and in using such a boiler as now described much higher pressures might be employed with confidence, on account of the great strength of the small tubes, the boiler having been proved by water pressure up to 3000 lbs. per square inch.

Mr. J. Murphy considered tubular boilers were decidedly superior in principle to plate boilers for high pressures, on account of their greater safety and efficiency; they were in use in many American steamers, where the tubes were all of the same diameter and joined at the ends by curved bends screwed on, giving a continuous passage through the tubes. He enquired how the junctions were made in the boiler now described, and whether there would not be some difficulty in getting out any part of the boiler for repairs, on account of the number of joints.

Mr. Perkins replied that each section of the boiler was connected by a single vertical pipe at top and bottom to the main cross tubes, and this connecting pipe had a right-handed thread at both ends, the thread being made long enough to allow of completely detaching any section without interfering with those on either side. The immediate vertical connecting pipes were all fixed with right and left handed screws. The boiler tubes were $2\frac{1}{4}$ inches bore and $\frac{3}{8}$ inch thick, and were butt welded so as to have the same thickness throughout and sufficient to allow of screwing; and the connecting pipes were $\frac{7}{8}$ inch bore and $\frac{1}{4}$ inch thick. Thin tubes were generally liable to be defective in material, but these were such as he had used extensively for many years in hot water warming apparatus working under high pressure with complete safety.

Mr. F. J. Bramwell had seen the engine at work and considered it useful and interesting in illustrating the economy of steam power by using increased pressure and greater expansion. The mode of estimating the evaporative duty of the boiler by measuring the consumption of water with a meter he thought was liable to error if not checked by observing the total increase of heat in the condensing water, in order to allow for water carried over as priming, which otherwise made the evaporative results appear greater than they really were. It was necessary to adopt this check in calculating the

evaporative duty, because priming was sure to occur, except in boilers with very large steam room where there was no violent ebullition. He had known an instance where the boilers in some of the American steamers, made with a number of vertical tubes, had been stated to give a very high evaporative duty; but when their actual performance was tested with a meter, it was found that 43 lbs. of water were fed into the boiler per indicated horse power per hour, which certainly could never have been all converted into steam, but showed that priming must have taken place extensively, and that the apparent high evaporative duty was a mistake.

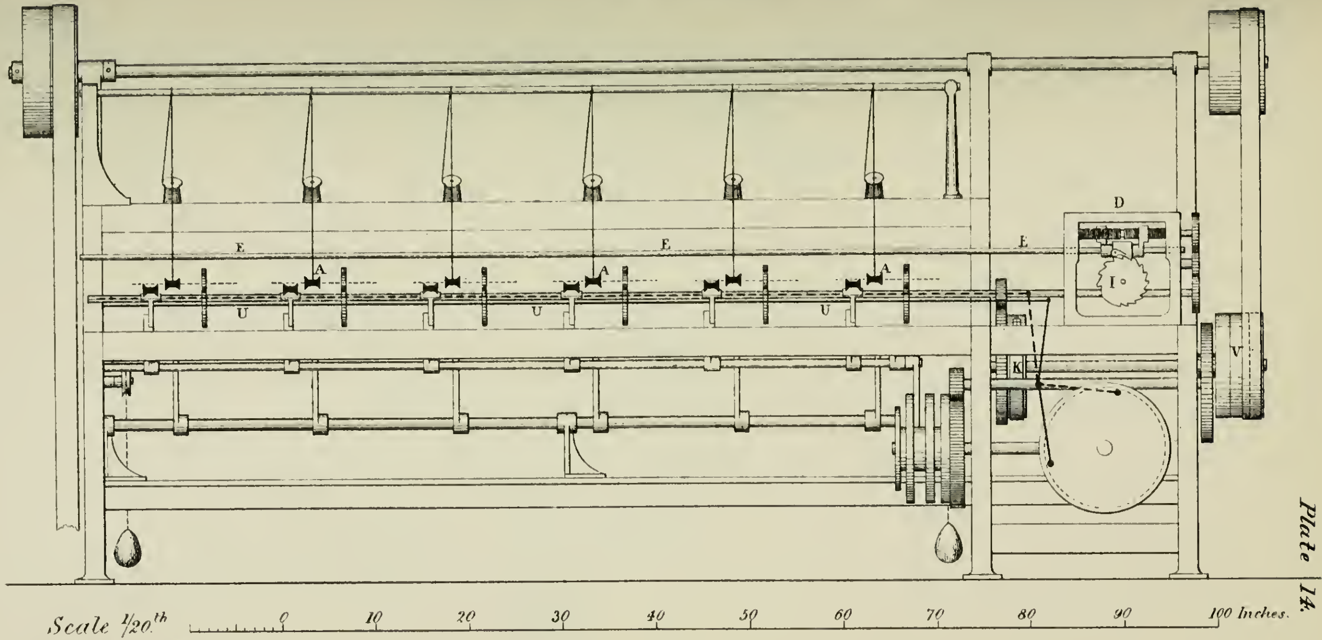
Mr. E. A. Cowper observed that vertical tubular boilers were especially liable to priming, from the comparatively small area of water surface for the liberation of the steam.

He proposed a vote of thanks, which was passed, to Dr. Williamson and Mr. Perkins for their paper, and hoped it would lead to the further development of the important advantages of high pressure steam with great expansion.

The Meeting then terminated.

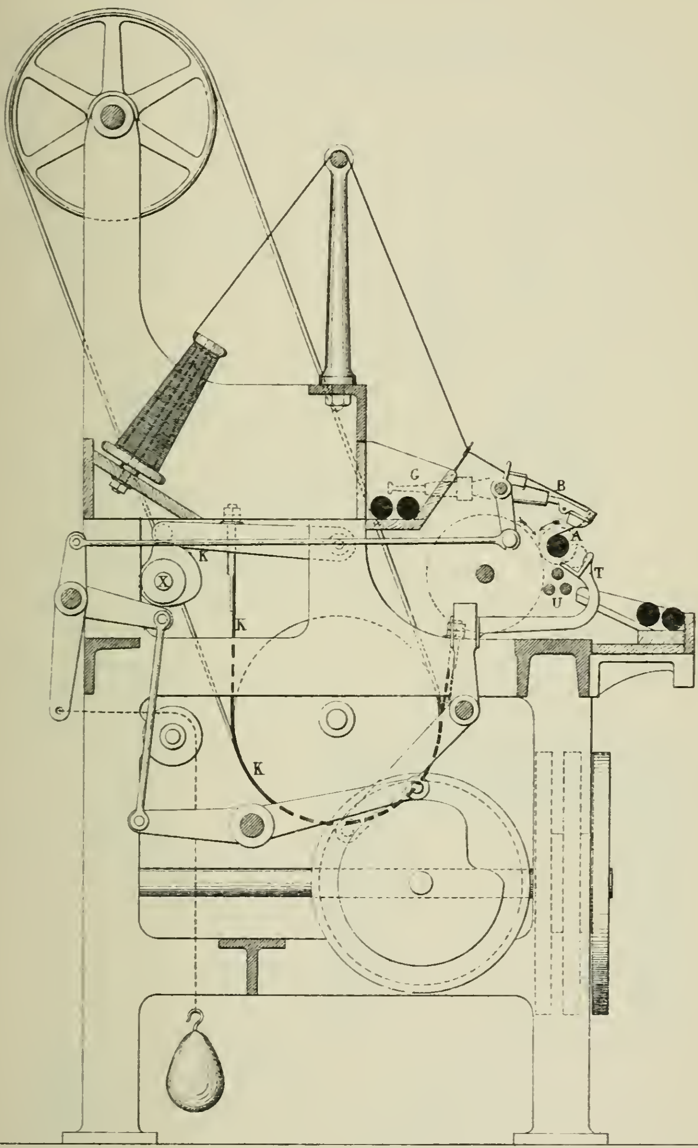
SPOOLING MACHINE.

Fig. 1. *Front Elevation.*



(Proceedings Inst. M.E. 1861. Page 54.)

Fig. 2. *Transverse Section.*



Scale 1/10th 0 10 20 30 Inches

(Proceedings Inst. M. E. 1861. Page 54)

SPOOLING MACHINE.

Plate 16.

Fig. 3. *Detail of Winding, Thread-Fixing, and Spool-Changing Apparatus.*

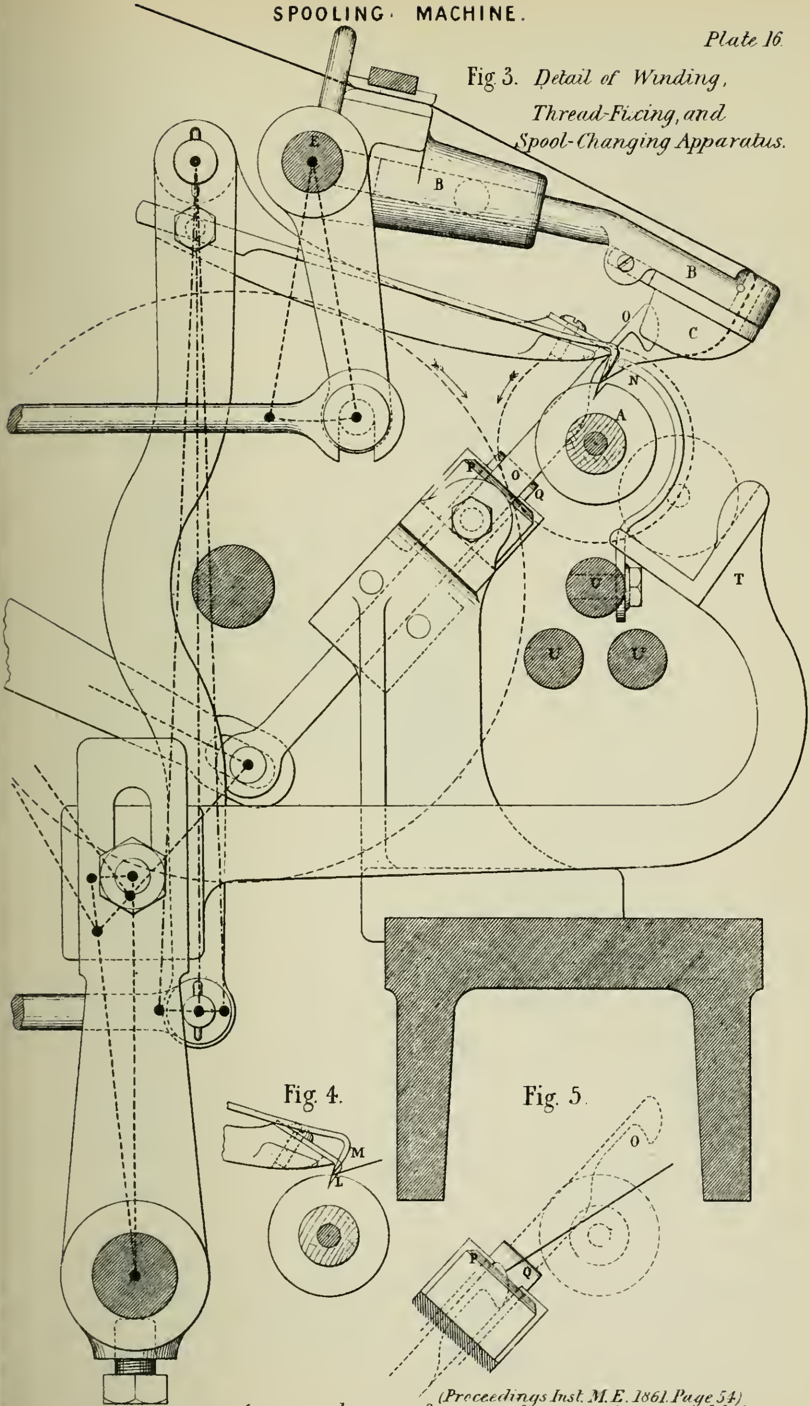


Fig. 4.

Fig. 5.

Scale ½. 0 1 2 3 4 5 *Inches.*

(Proceedings Inst. M.E. 1861. Page 54.)

SPOOLING MACHINE.

Fig. 7. Thread Fixing.

Fig. 6. *Front Elevation of Winding Apparatus during process of Winding.*

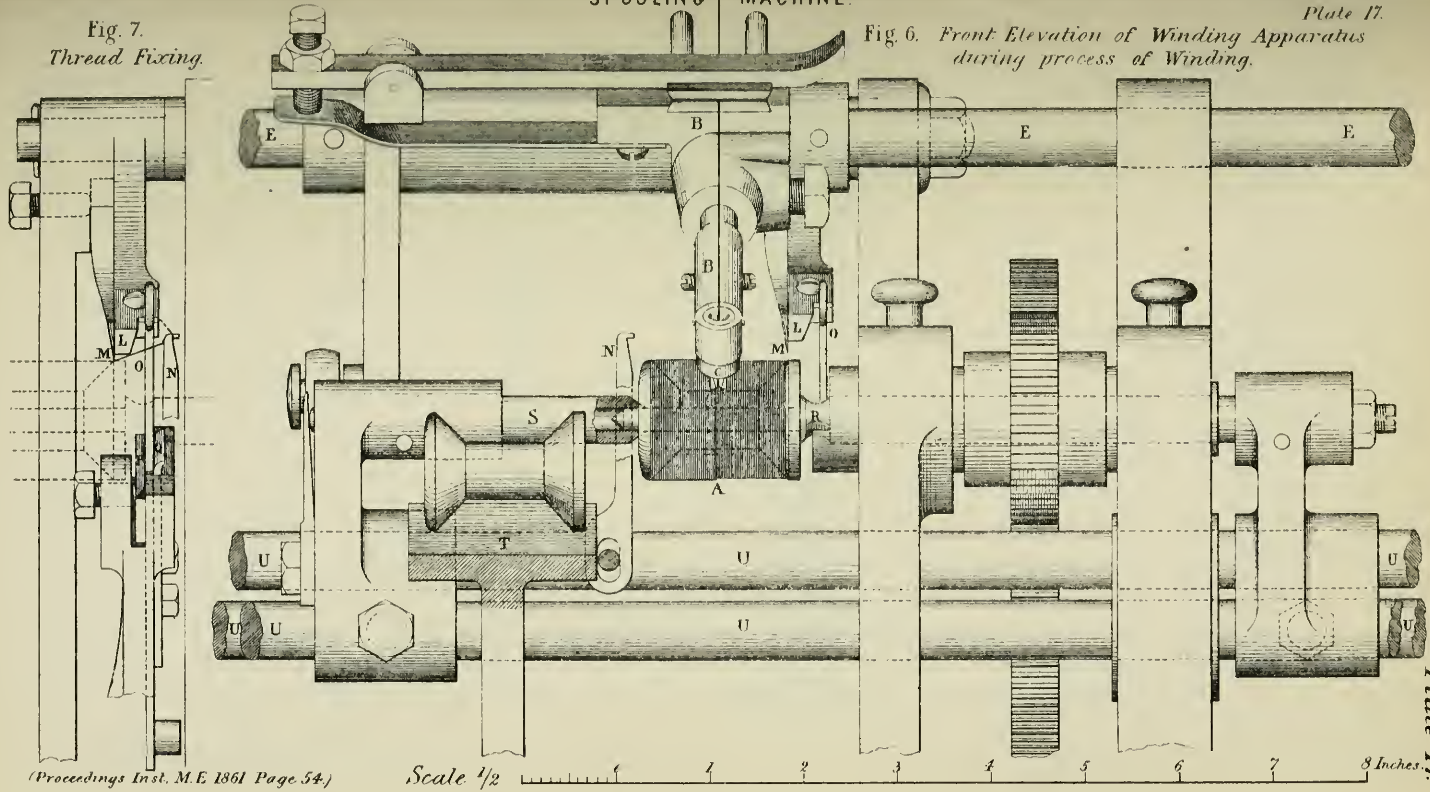
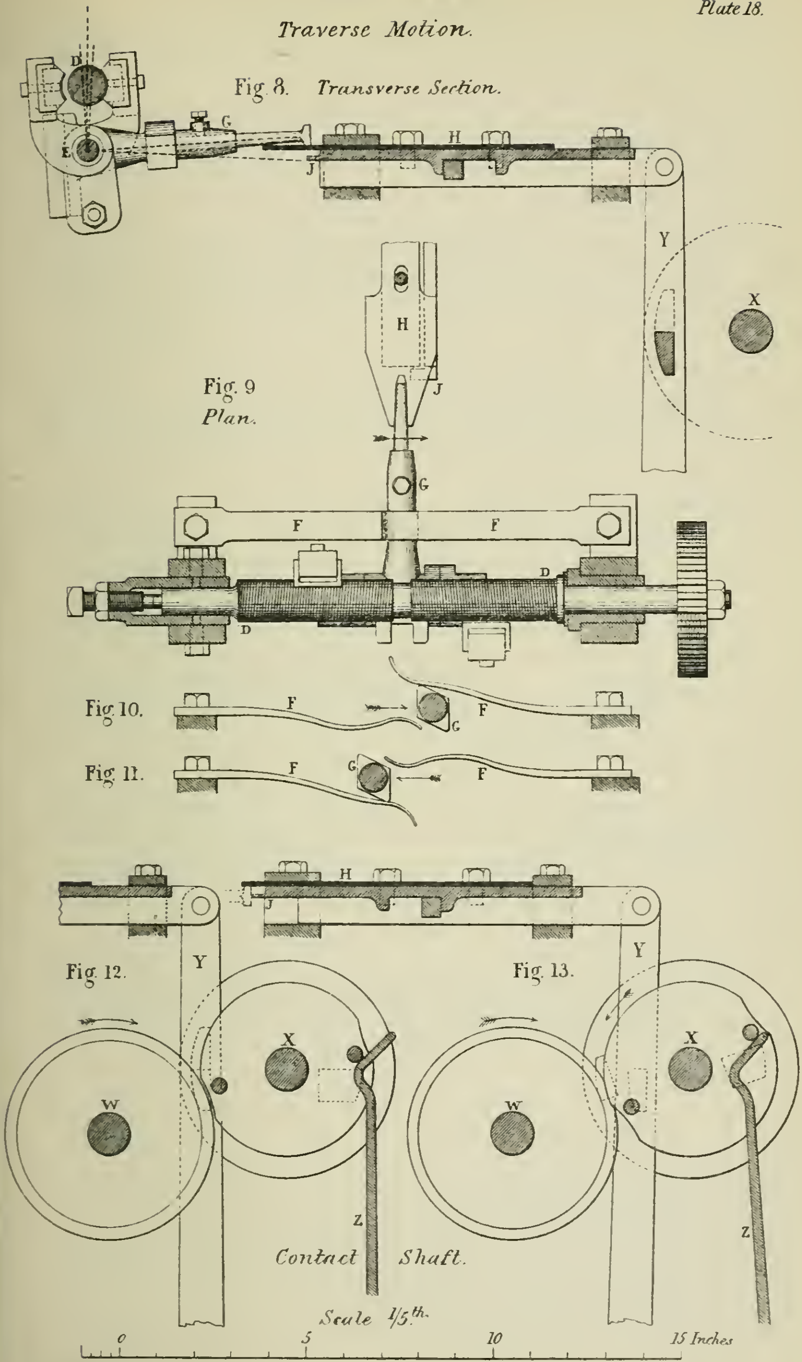


Plate 17.

SPOOLING MACHINE.

Plate 18.

Traverse Motion.



Diagrams of Cams performing Change Movements

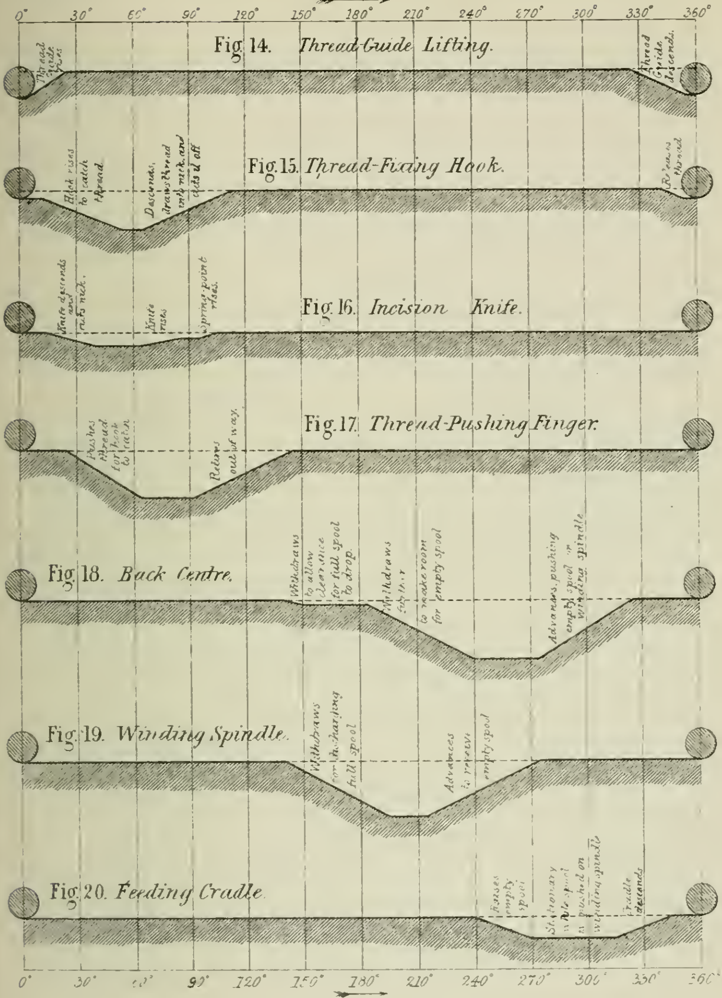
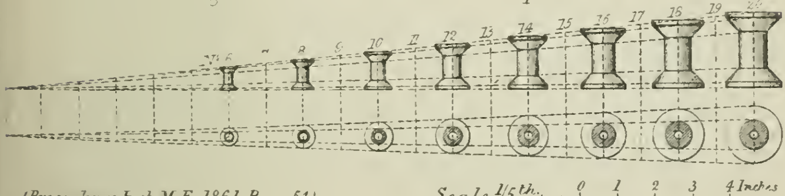


Fig. 21. *Scale of Sizes of Spools.*



(Proceedings Inst. M. E. 1861 Page 54) *Scale 1/5th.* 0 1 2 3 4 *Inches*

COKE OVENS.

Plate 20.

Fig. 1. *General Elevation of Eaton's new Coke Ovens.*

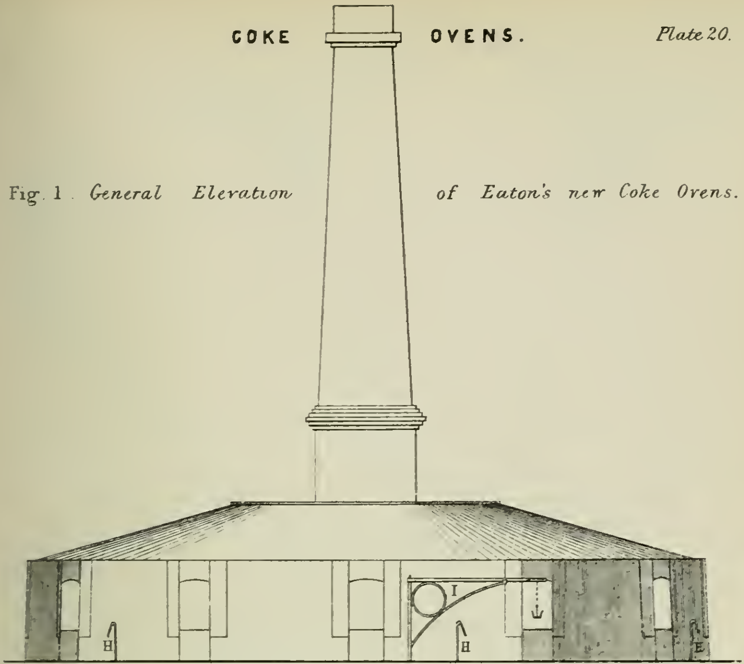
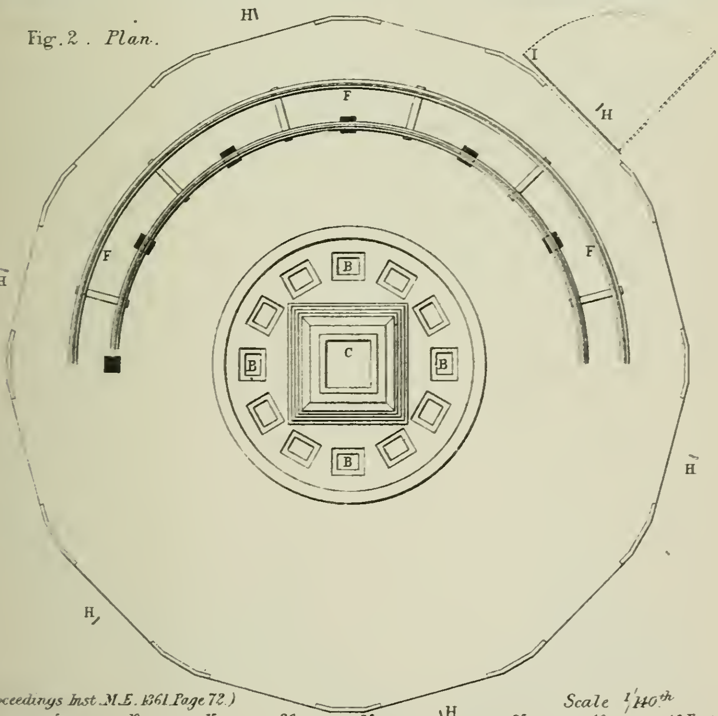


Fig. 2. *Plan.*



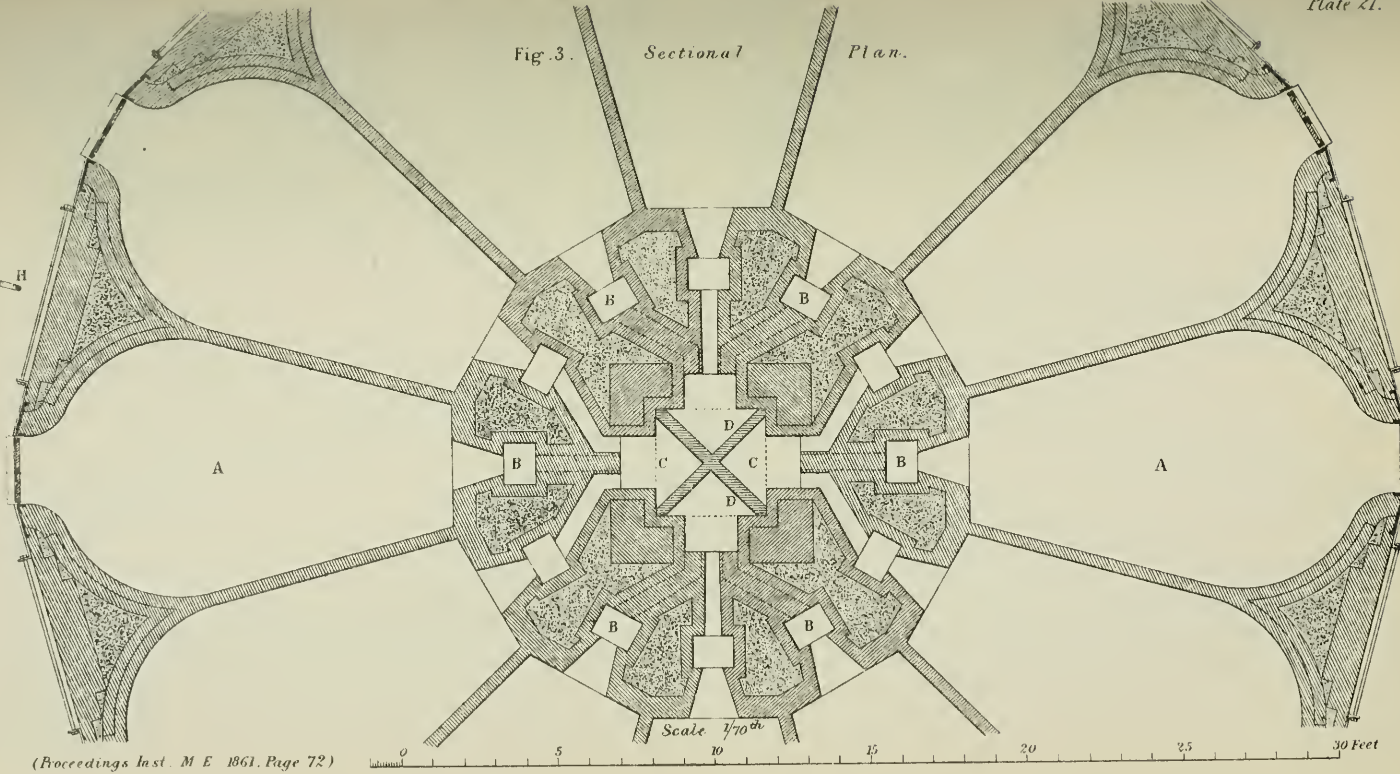
(Proceedings Inst. M.E. 1861 Page 72.)

Scale 1/40th

0 5 10 15 20 25 30 35 40 45 Feet

COKE OVENS.

Fig. 3. Sectional Plan.

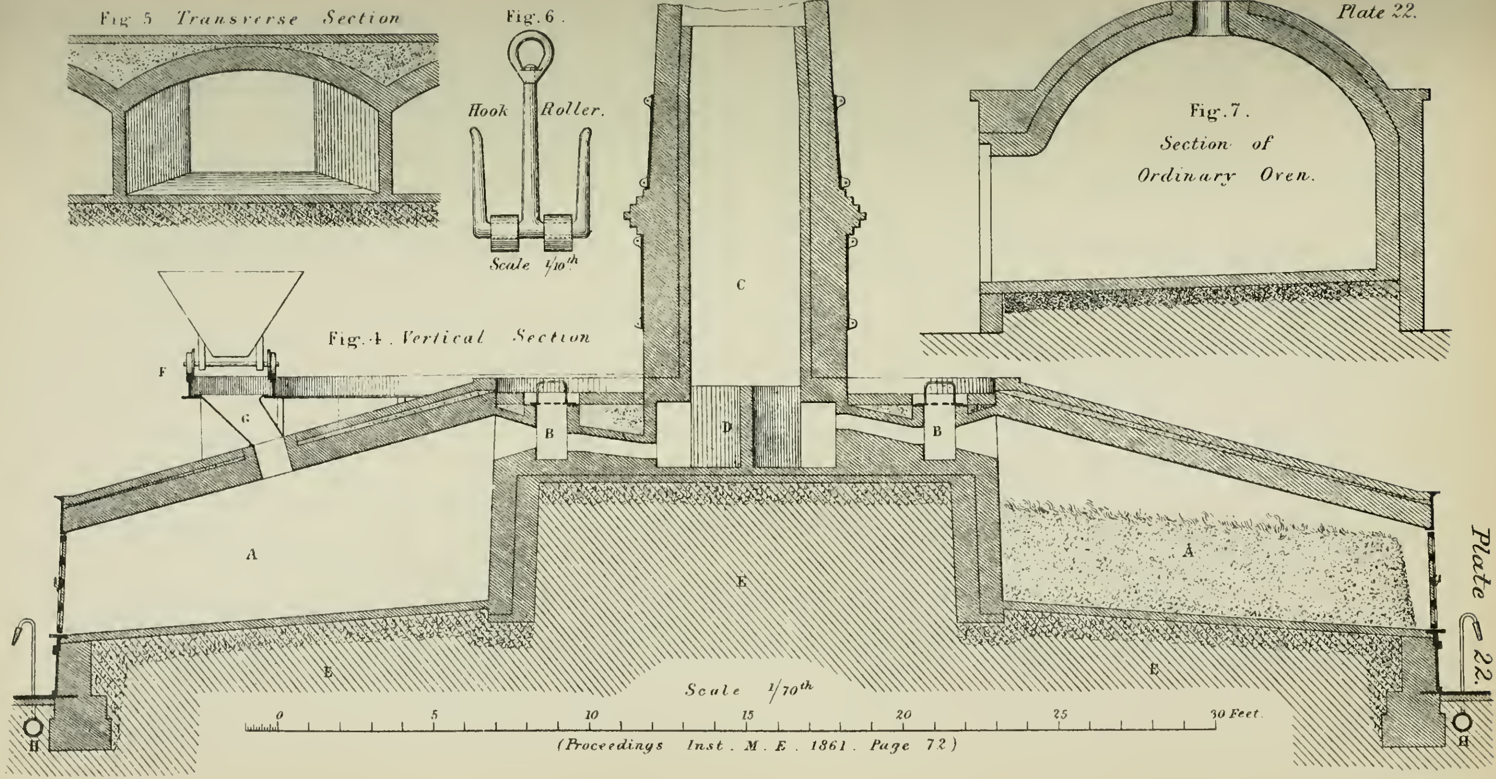


(Proceedings Inst. M E 1861. Page 72)

Plate 21.

Plate 22.

COKE OVENS.



(Proceedings Inst. M. E. 1861. Page 72)

HIGH PRESSURE STEAM ENGINE.

Fig. 1. *Elevation of Boiler*

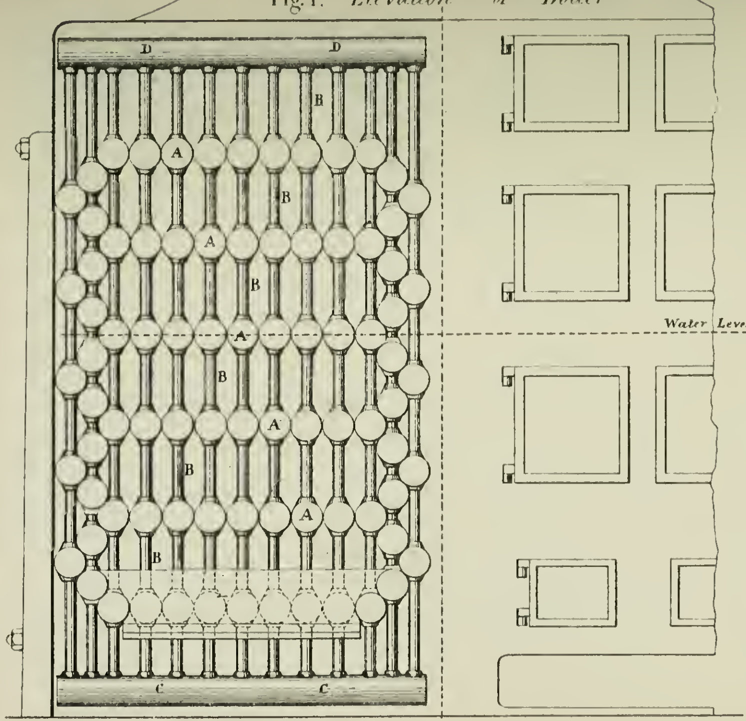
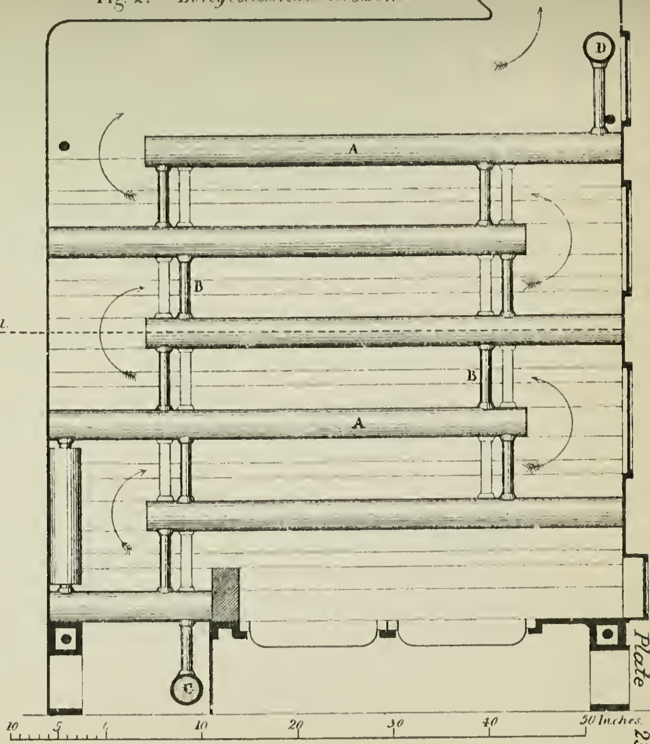


Fig. 2. *Longitudinal Section*



Scale 1/20th

(Proceedings Inst. M.E. 1861. Page 94.)

HIGH PRESSURE STEAM ENGINE.

Vertical Sections of Engine.

Fig 3. *Transverse Section.*

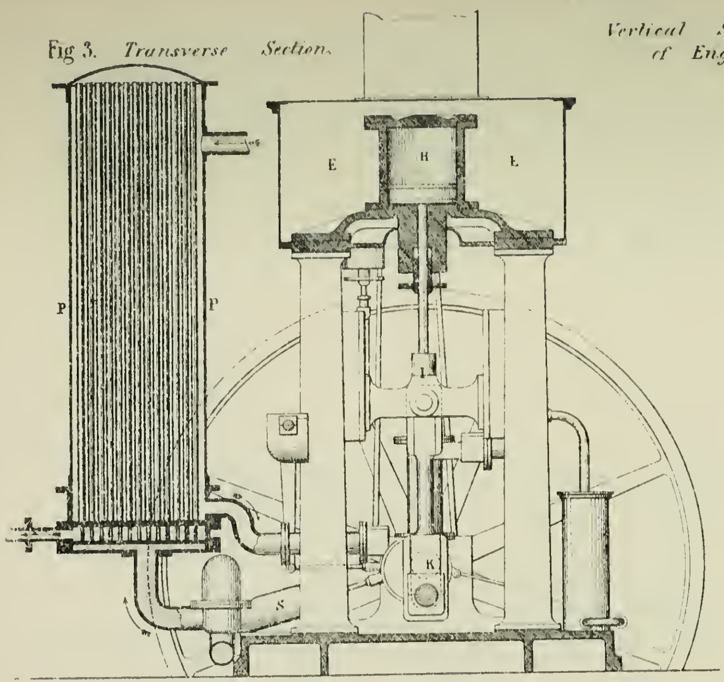
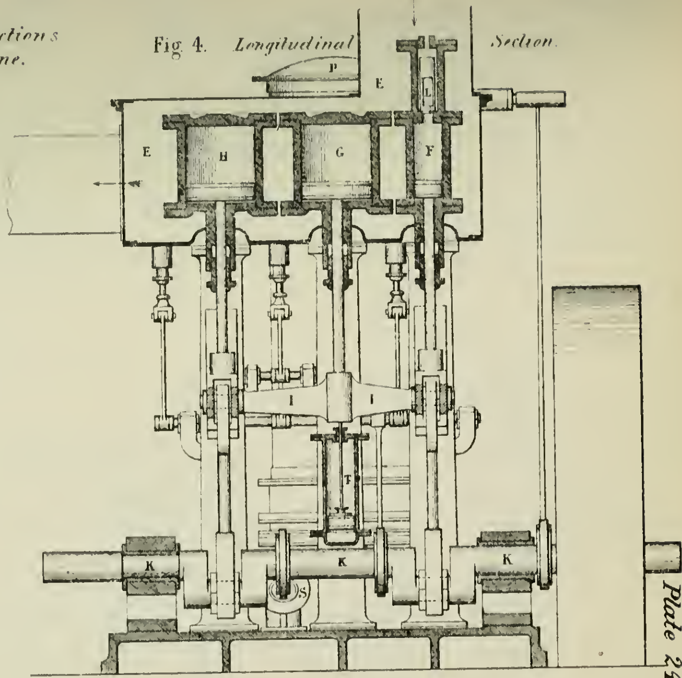


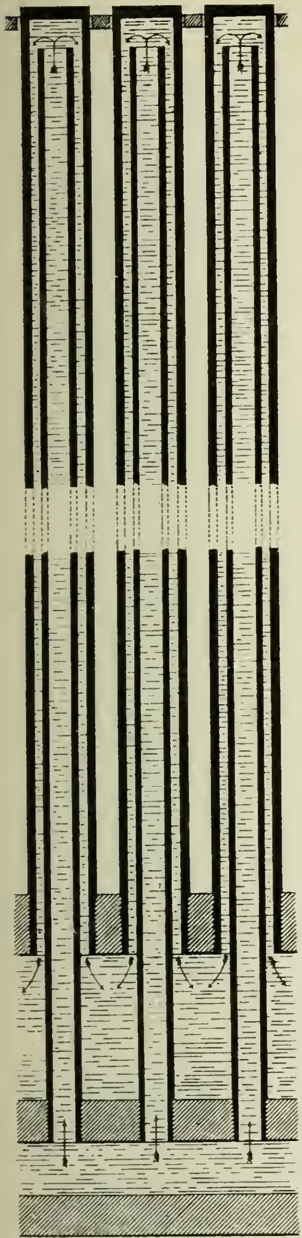
Fig 4. *Longitudinal Section.*



Scale $^{1}/_{40}{}^{th}$ 10 0 50 100 150 *Inches.*

Plate 24.

Fig. 5. Vertical Section of Surface Condenser.

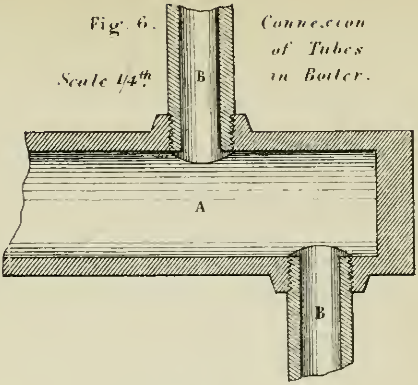


Scale 1/4th

0 1 2 3 4 5 Inches.

Fig. 6. Connexion of Tubes in Boiler.

Scale 1/4th



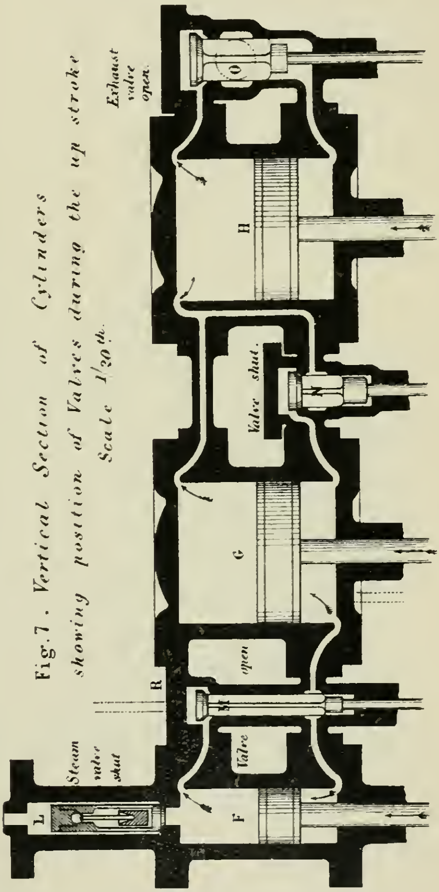
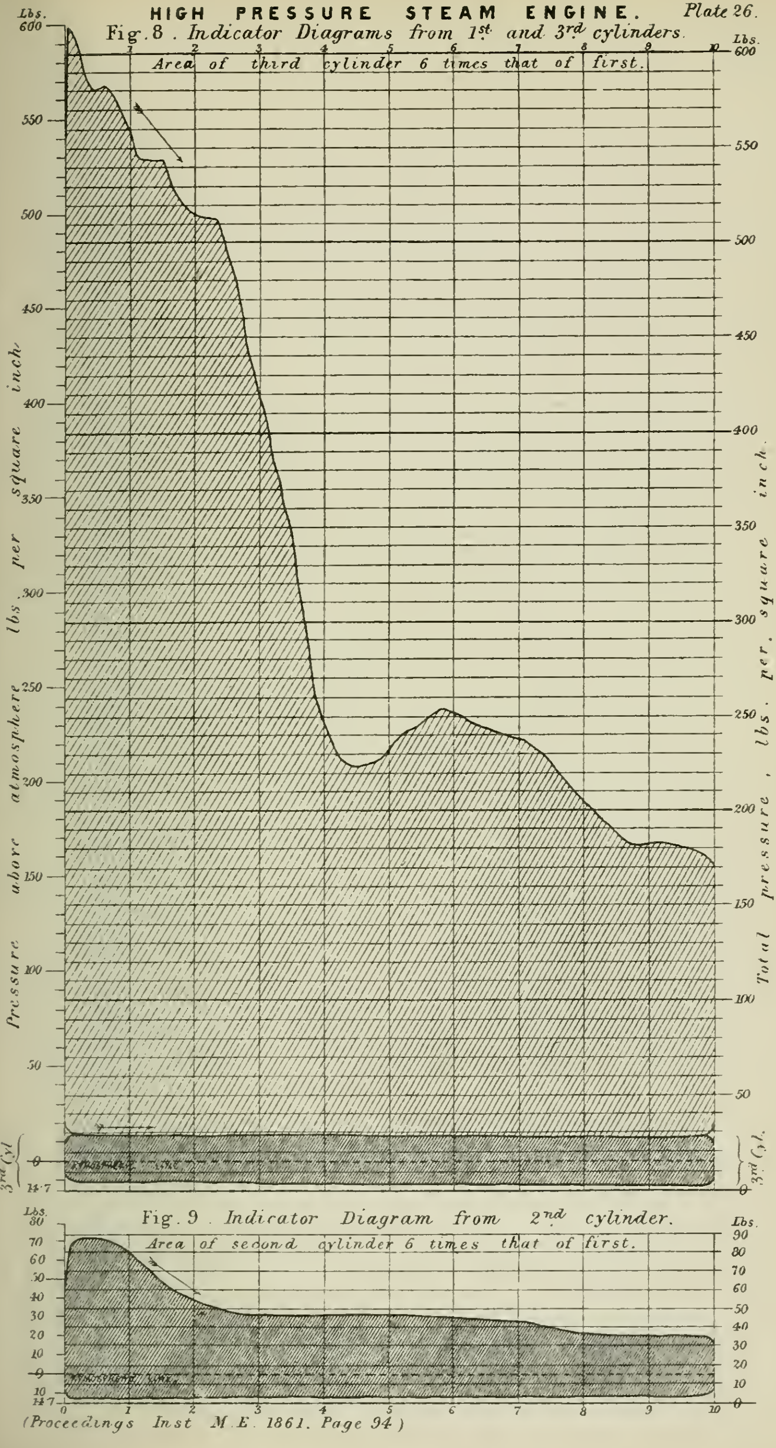


Fig. 7. Vertical Section of Cylinders showing position of Valves during the up stroke

Scale 1/20th.



HIGH PRESSURE STEAM ENGINE.
Plate 26.
Fig. 8. Indicator Diagrams from 1st and 3rd cylinders.
Area of third cylinder 6 times that of first.
Lbs.
Pressure above atmosphere lbs. per square inch
Total pressure, lbs. per square inch
3rd Cyl.
Fig. 9. Indicator Diagram from 2nd cylinder.
Area of second cylinder 6 times that of first.
(Proceedings Inst M.E. 1861. Page 94)

PROCEEDINGS.

31 July and 1 August, 1861.

The Annual Provincial Meeting of the Members was held in the Music Hall, Surrey Street, Sheffield, on Wednesday, 31st July, 1861; Sir William G. Armstrong, President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

George Addenbrooke,	Darlaston.
Henry Bessemer,	Sheffield.
William Esson,	Cheltenham.
Sampson Lloyd Foster,	Wednesbury.
Edward Green, Jun.,	Wakefield.
William Haden,	Dudley.
Peter Haggie,	Gateshead.
Joseph Bennett Howell,	Sheffield.
Robert Jackson,	Sheffield.
Thomas William Jeffcock,	Sheffield.
Joseph Mitchell,	Worsbro' Dale.
Loftus Perkins,	London.
Thomas William Plum,	Blaenavon.
Thomas Edward Vickers,	Sheffield.

HONORARY MEMBER.

Alexander W. Williamson,	London.

The President then delivered the following address:—

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ADDRESS OF THE PRESIDENT.

The era of Mechanical Engineering may be regarded as dating from the period when the Steam Engine first became applicable through the genius of Watt to the production of continuous rotary motion. The introduction of separate condensation, which had previously been effected by that great man, may justly be considered the chief foundation of his fame. But it was not until he had succeeded in converting the reciprocating movement of the piston into rotary action that the steam engine became available for every variety of purpose requiring the employment of motive power.

While Watt was thus engaged in rendering the steam engine capable of universal application, the great invention of Arkwright, the author of the modern system of spinning, was struggling into notice. This was quickly followed by that of Cartwright, the designer of the power loom, which marked a new era in the art of weaving. These inventions were each destined to play a part of incalculable importance to mankind, and to afford employment to the giant power which Watt had raised from infancy to maturity. They have distributed cheap and abundant clothing over the face of the earth; and while they have conferred so great a boon on the whole human race, they have been and still continue to be the chief source of this country's wealth. These great advances in textile manufactures were purely utilitarian in their character. It was reserved for France to complete the work, and extend the humanising influence of ornament and taste, by giving birth to the Jacquard loom.

Nearly simultaneous with these inventions were those of Cort, which though of a widely different character have produced fruits of equal importance. They have had the effect of enormously facilitating the conversion of cast iron into the malleable form, and have enabled

us to roll it into bars of every variety of section, thus paving the way for the introduction of railways, and rendering iron available for the construction of ships, and the various structures on land in which it is now employed. Following down the history of the manufacture of iron from the days of Cort, we come at a later date to the introduction of the steam hammer by Nasmyth, and of the hot blast by Neilson. The former has rendered practicable the fabrication of those large masses of iron which are now daily required in the construction of heavy machinery; while the latter has had the effect of diminishing the cost and extending the application of the material.

Turning next to the subject of Steam Navigation, we find that the first attempt to propel a vessel by steam was made by Miller, on the Forth and Clyde Canal, soon after the adaptation of the steam engine to rotary motion by Watt. At a somewhat later date, though with more success, Fulton constructed a steam vessel in America: but the achievements of both were feeble foreshadowings of that mighty growth, which in the course of half a century has covered the ocean with steamers; advancing step by step from an insignificant boat on the Clyde to that wonder of our age, the "Great Eastern" steamship. This great development, although so rapid, has nevertheless been so gradual that the adoption of the screw propeller is the only prominent feature in its progress. The introduction of the screw, which is chiefly due to the perseverance and enterprise of Francis Smith, has rendered the power of steam available for war vessels, while in sea-going steamers generally it seems destined to displace entirely the earlier invention of the paddle.

As in the case of steam navigation, the propulsion of carriages by steam power on land had its origin in very small beginnings. From the days of Watt, who first suggested the application of the steam engine for this purpose, up to the time when George Stephenson, the illustrious first President of this Institution, devoted with wonderful perseverance the inventive powers of his mind to its perfection, the Locomotive Engine had attained no practical value. But in the hands of Stephenson it took as great a stride as did the condensing engine in the hands of Watt. The ever memorable "Rocket," which carried off the prize at the opening of the Liverpool and Manchester Railway,

became the type of all succeeding locomotives, just as the condensing engine as left by the original master has remained the standard of that class of engines. Of all the achievements of mechanical engineers the locomotive engine is the greatest. As a work of skill it presents the most remarkable instance of strength and power, combined with lightness, that can be found in the whole field of mechanical engineering; while in point of utility it has served more than any other invention to develop the resources of every country in which it has been employed.

By promoting centralisation, steam communication has made good government cheaper and more practicable. It has strengthened the hands of the executive, broken down provincialism, opened out new markets for produce, established new fields of supply, equalised prices, and facilitated colonisation. It has given fresh life to old nations, and added to the vigour of new ones. A Greek poet with seemingly prophetic import has described the business of the road-making sons of Vulcan to be that of converting the uncivilised places of the earth into civilised. True sons of Vulcan, the god of iron and of fire, are those men who in our time have been the pioneers of civilisation, by giving steam-worked railroads to the world, and applying the steam engine on the highways of the ocean.

While the steam engine was being applied to manufacturing purposes and to locomotion on land and by water, there was one branch of industry in which it remained neglected. Whether it be that ancestral usages are more reverenced by the owners and tillers of land than by the more progressive inhabitants of cities, or whether the steam engine was regarded by the rural population as an upstart rival of the horse, with which their pleasures and pursuits were so much associated, certain it is that the cultivators of the soil were the last to resort to the agency of steam. But agriculture is now added to the domain of science, and under her sway the steam engine has been applied to numerous purposes of husbandry. Some of these have involved peculiar difficulties, and perhaps in no case have the resources of mechanics been more severely taxed than in applying steam power to the operation of ploughing. Much interest at present attaches to this subject, in connection with the recent exhibition of the Royal

Agricultural Society at Leeds, and the successful results obtained on that occasion by Fowler and by Howard, both members of this Institution.

The development of these several inventions has involved the necessity of great improvements and refinements in tools and constructive machinery; and the name of Whitworth, another of your Presidents, will go down to posterity as that of the man who has been chiefly instrumental in raising to its present height this important branch of mechanical engineering. But it must not be forgotten that, whatever may be the perfection of tools, manual dexterity will ever be the foundation of excellence in construction; and if the skill of the artificer had not kept pace with the progress of invention, the mechanical productions of the present day would not have been possible. It is a proud reflection for Englishmen that nearly all the names connected with the wonderful series of mechanical triumphs to which I have adverted have been those of their fellow countrymen; and this fact is the more remarkable when we consider that in earlier times our country had been singularly sterile in the production of this species of talent.

In thus glancing at the history of mechanical science during the last eighty years, we see how entirely our successes have been based upon the possession of that metal with which nature has supplied us in the greatest abundance. Without iron all our skill and ingenuity would have resulted in comparatively nothing; and had it not been endowed with that singular property of hardening by sudden immersion after previous conversion into steel, we should have been deprived of the means of cutting and shaping it to those accurate forms which mechanical constructions require. Its property of welding is almost equally essential to its utility; and the combination of these remarkable qualities in one metal, coupled with the fact of its natural localities being generally identical with those of coal, affords the most striking instance of adaptation to the purposes of man that can be found in the mineral kingdom. It is the iron and not the golden age which is the true age of civilisation; and England has led the way in the march of progress, chiefly through her skill and energy in producing this metal and applying it to mechanical purposes.

Iron, unlike all other metals, has three phases of existence: cast iron, wrought iron, and steel: each equally useful, and yet so different as to be virtually separate metals. In the manufacture of steel the town of Sheffield enjoys an unrivalled eminence, and our discussions on this occasion will naturally be directed to those various questions of peculiar interest which at present apply to that most useful product.

I have hitherto spoken of the mechanical arts as applied only to the purposes of peace; but I have yet to refer to the darker side of the picture in speaking of their application to the purposes of war. We shall all agree in condemning war, and deploring the suffering it entails; but we must not regard it as destitute of all admixture of good. The conquests of ancient Rome scattered the germs of civilisation over the whole of the then known world, and similar effects have attended many of the conquests of more modern times. War also affords a field for the exercise of some of the noblest attributes of our nature: courage, patriotism, self-devotion, and honour, have found their brightest examples amongst those who have followed the profession of arms: and the homage which is universally paid to military distinction shows how contrary to our instincts are the tenets of those moralists who place war and crime in the same category. But whatever opinions may be held on this subject, it is useless to take utopian views of the duties of nations and the principles which ought to regulate their intercourse. We know that nations, like individuals, are liable to quarrel; and when they do so, having no common jurisdiction to control them, they resort to arms. So long therefore as any one nation maintains its armaments, it is an absolute necessity that others should do the same, unless they choose, by their inability to resist, to tempt a rupture, and are content to succumb in the event of its occurrence. Our neighbours the French, always forward in everything appertaining to war, have of late years devoted their energies to two most important subjects: the rifling of ordnance, and the application of defensive armour to ships. Their advances have necessitated similar steps on our part, and we have certainly no reason to suppose that we are behind them in the race.

With the first of these subjects I have been personally much concerned, and I have also had opportunities of observing the merits and defects of the various descriptions of armour plates with which experiments have been made by the direction of government. I need scarcely say that up to the present time cast iron has been almost exclusively employed in the construction of heavy ordnance; but guns made of that material have not been found adequate to resist the more severe strain incident to the use of elongated rifled projectiles. This inadequacy of strength becomes the more decided as the magnitude of the gun is increased, and since a growing demand exists for more powerful artillery, the use of cast iron for its construction seems to be entirely precluded. It is said, and I believe with truth, that in America the manufacture of cast iron ordnance has been so far improved by applying water to cool the casting from the interior, as to enable serviceable guns of this material to be produced of much larger bore than have been made in England. But it appears that these guns have not been rifled, and are intended to be used only with hollow projectiles. This success therefore affords no reason for coming to a different conclusion as to the unfitness of cast iron for the construction of rifled guns designed to project solid shot, especially when the dimensions are large. Even when strengthened by wrought iron hoops, the tendency of cast iron in a gun is to become weaker by every succeeding discharge. This is owing to minute fractures occurring in the bore, generally near the vent, and gradually extending until they terminate in the rupture of the gun. If therefore cast iron guns are to be made available at all as rifled ordnance, it can only be by confining their use to hollow projectiles and light charges.

But if the same indulgence were extended to wrought iron guns, equal efficiency would be obtained with half the weight of metal; and on this ground alone the superiority of the latter is decisive. Wrought iron, made either from bloom or from puddled ball, must necessarily consist in the first instance of a congeries of welds or joinings. The smaller the mass and the more it is reduced under the rolls or hammer, the more perfectly will it be united; but when a large block is forged from an aggregation of blooms it is almost impossible to render it homogeneous throughout. The flaws in such a forging will

generally be drawn out by the process of hammering in the direction of the length, and will therefore not materially affect its strength in reference to longitudinal strains: but if the mass be subjected to an explosive force acting from the interior, as in a gun, the presence of such flaws becomes fatal. Wrought iron therefore applied as a solid block to the construction of guns I hold to be even more objectionable than cast iron; for although a wrought iron gun thus made, if it happen to be sound, may possess greater powers of resistance, yet it must always be more subject than cast iron to concealed flaws, and on that account be more uncertain and treacherous. If iron after its conversion to the malleable form could be fused, all welds would be obliterated and the mass rendered uniform throughout. Such a material would merit the appellation of homogeneous iron; but the metal which now bears that name is of a different nature, being merely a species of cast steel.

The crystalline form assumed by steel in solidifying from the liquid state always renders the material in the first instance hard and brittle; and it is only in the subsequent process of hammering that it acquires ductility and toughness. This alterative process of hammering is perfectly effectual when the thickness of the steel is small; but when it is wanted to be forged in a large mass it appears to be a matter of the utmost difficulty to effect the required change. It is seldom that the enterprise of English manufacturers is exceeded by that of foreigners, but in the production of steel forgings of large dimensions Krupp of Essen has taken the lead of all steel makers in this country. He has met the difficulty of toughening large masses of cast steel by using hammers of extraordinary weight; and I believe that equal success will never be attained in England without adopting similar measures.

It will be a great era in metallurgy when a material possessing the toughness and ductility of wrought iron combined with the homogeneous character of a cast metal can be economically supplied in large blocks. But whatever the march of improvement may effect, I doubt whether such blocks can yet be produced at a cost which would admit of their extensive application. I am glad however to see that papers are to be read at this meeting which may be expected to bear upon this important

subject; and amongst the names appended to those papers we are fortunate in having that of Bessemer, whose exertions in this field of enquiry have attracted so much attention.

The preceding observations on the application of iron to the construction of artillery would not be complete without some allusion to the system of manufacture which I have myself adopted, which may be designated the "coil system." When malleable iron is rolled into bars, its crystallisation assumes a fibrous form, causing the bar to resemble a bundle of threads, strongly adhering to each other, but possessing their chief tenacity in the direction of their length. The compressing power of the rolls is also such as generally to eliminate all imperfect welds, or if any remain they are drawn out parallel with the fibre of the iron. To realise in a cylinder the advantage of this fibrous structure, it becomes necessary to coil the bar into a spiral, and to unite the folds by welding. The lines of welding will then be nearly transverse to the cylinder, in which direction they have little tendency to weaken it when exposed to a bursting force, even should they not be perfectly sound. There is a limit to the thickness of bar which it is convenient to bend into a spiral; and in making a gun on this system the required diameter is made up by applying successive layers of coils, each layer being shrunk upon the one beneath. This mode of construction has the advantage of affording the opportunity of discovering and rejecting all defective parts as the work proceeds; and guns may be thus built up to almost any size without encountering any of those difficulties and liabilities which are met with in forging large blocks whether of steel or iron.

With regard to the great question as to the ultimate effect of artillery against ships protected by defensive armour, I believe that whatever thickness of iron may be adopted guns will be constructed capable of destroying it. At the same time I am of opinion that iron-plated ships will be infinitely more secure against artillery than timber ships. The former will effectually resist every species of explosive or incendiary projectile, as well as solid shot from all but the heaviest guns, which can never be used in large numbers against them. In short it appears to me to be a question between plated ships or none at all, at any rate so far as line-of-battle ships are concerned.

With respect to the quality of the material best adapted to resist the impact of shot, this subject is engaging much attention in the town of Sheffield and the iron districts generally. So far as my own observation and experience go I may say that hardness and lamination are the conditions most essential to avoid. In striking a plate the tendency of a shot is to fracture rather than to pierce the material. When penetration is effected the hole is of a broken character, and not such as would be made by the cutting action of a punch. The softer the iron therefore the less injury it will sustain; and I apprehend that steel in every form will from its great hardness be found less effective than wrought iron, while its cost would be very much greater. As regards lamination it has been clearly ascertained that a given thickness of iron made up of successive layers of thin plates is very much weaker for the purpose of armour than the same thickness in the solid form. But a laminated plate, by which I mean a plate having the layers composing it imperfectly united, must be regarded as an aggregation of separate plates, so that the strength derived from continuity is wanting. If this tendency to lamination could be obviated, rolled plates would in my opinion be preferable to forged, since the iron would acquire a more fibrous condition; but the existence of this liability appears to turn the scale in favour of forging. I hope the time is far distant when these great questions concerning attack and defence may receive a practical elucidation in actual warfare; but I trust that in the course of our efforts to solve them, discoveries may be made which will be as useful for the purposes of peace as for those of war.

Before concluding, I am tempted to advert to a subject intimately connected with mechanical progress, but upon which much difference of opinion may exist. That dauntless spirit, which in matters of commerce has led this country to cast off the trammels of protection, has resulted in augmented prosperity to the nation, showing the injurious tendencies of class legislation when opposed to general freedom of action. Would that the same bold and enlightened policy were extended in some degree at least to matters of invention. Under our present patent laws we are borne down with an excess of protection.

We are obstructed in every direction by patented inventions which will never be reduced to practice by those who hold them, but which embrace ideas capable of useful application if freed from monopoly. The merit of invention seldom lies in the fundamental conception, but is to be found in the subsequent elaboration, and in the successful struggle with difficulties unknown to the mere theorist; which often require years of labour, blended with disappointment, for their removal. Nothing can be more irrational therefore than to accord equal privileges to the mere schemer and the man who gives actual effect to an invention. Primary ideas ought to be the common property of all inventors; and protection, if we are to have it at all, should be sparingly awarded to those persons alone who by their labour and intellect give available reality to such ideas.

Apart from the impolicy of the present indiscriminate system, its operation is unjust. Philosophers who furnish the light of science to guide to useful discovery go altogether unrewarded and unrecognised. Practical men, who like Watt and George Stephenson devote the best part of their lives to perfecting inventions of immense importance to the world, seldom derive from patents any greater emolument than would flow to them without the aid of a restrictive system; while they are frequently involved in tormenting litigation about priority of idea. On the other hand we see numerous cases of disproportionate wealth realised by persons whose only merit has been promptitude in seizing upon and monopolising some expedient which lay upon the very surface of things and required no forcing atmosphere of protection for its discovery. Finally, injustice is done by the existing law to those men who have no desire for monopoly, but who are compelled to become patentees for no other purpose than to prevent their being excluded from carrying their own ideas into practice.

For my part I incline to think that the prestige of successful invention would as a rule bring with it sufficient reward, and that protection might be entirely dispensed with. On this point however I speak with hesitation; but it is at all events certain that extensive reform is urgently required in this branch of legislature, and that the advance of practical science is now grievously obstructed by those very laws which were intended to encourage its progress.

Having now called to your remembrance the triumphs which have already been accomplished in mechanical science, and having directed your attention to some of the subjects which at the present time merit your consideration, it only remains to express my hope that the genius, enterprise, and intelligence, which have hitherto distinguished your profession may continue to bear fruits worthy of the past; and that the proceedings of this Institution may serve to guide and stimulate the efforts of its members.

Mr. J. Fenton moved a vote of thanks to the President for his address, which was passed.

The following paper was then read:—

ON THE MANUFACTURE OF STEEL RAILS AND ARMOUR PLATES.

By Mr. JOHN BROWN, of Sheffield.

Steel Rails.—One of the most important items in the cost of railway maintainance is the renewal of Rails, and it is therefore natural that much attention should have been paid to the various methods proposed for giving greater durability to the rail. It is unnecessary to enter into any statement of facts as to the short time that ordinary rails last when exposed to the wear of main lines: experience has shown the want of some means by which their duration could be prolonged, and in the manufacture of rails it is now always expected that the quality of the material and the method of piling shall be distinctly stated before any large amount of work is undertaken.

No ordinary material or method of piling or making the finished rail will however resist the crushing action of modern locomotives, and extraordinary means have been sought to accomplish this much desired object. Amongst the most important of the methods hitherto used for this purpose is that of forming the wearing surface of the rail entirely of steel, by introducing a bar of steel into the pile and rolling it out so as to unite it with the iron body of the rail. Another method is to submit the surface of the ordinary iron rail to a process of conversion in a furnace specially adapted, thereby casehardening the outer coat or skin of the wearing portion of the rail. Both of these processes have many advocates, and to a certain extent they fulfil their object; still they are open to the serious objection that only the crust or skin of the rail is rendered hard, and they do not prevent the body of the rail from yielding to the severe pressure of the wheels; lamination and splitting are only to a small

extent diminished, and though the life of the rail is prolonged, the prolongation is uncertain. The same objections apply to the puddled steel rail, and it is also liable to vary considerably in its hardness and to be at times too brittle for perfect safety. This liability to vary in quality is inseparable from the mode of manufacture as at present practised; and though many very good rails of this kind have been produced, the want of certainty in the manufacturing process seriously diminishes its value.

The introduction however of Bessemer's system has opened out a mode of producing a pure homogeneous hard and tough material, most admirably suited for the manufacture of rails; and though their cost may for a time prevent their being extensively used, there is no doubt that on every railway there are certain places where they would be laid with economy, where the traffic is so constantly severe that ordinary points and crossings have to be renewed on an average four times a year. Once laid of cast steel rails, they would give no trouble for many years.

In the Bessemer process the pig metal is reduced in a reverberatory furnace, and is then run by a trough into the blowing or converting vessel, in which air is forced through the fluid metal for about 20 minutes, or until the fluid pig is almost entirely decarbonised. A small quantity of melted pig containing a known proportion of carbon is then added, and the charge of converted metal is then transferred to a ladle from which it is poured into ingot moulds, not however by the usual mode of canting the ladle, but by opening a valve in the bottom of the ladle, which allows only the pure metal to run out into the moulds. The ingots are cast of such weight and form as are necessary for the production of each rail. Thus for a 6 yard rail of 84 lbs. per yard, the ingot requires to be 9 inches square and 26 inches long. This ingot is hammered down to 6 inches square and 5 feet long, and then rolled in the ordinary way. It will be evident that the only limit to the length of the rail made in this simple manner is either the weight of the ingot which can be produced or the length of the rolling mill or heating furnace. It is as easy to produce long lengths as short ones; and in this respect the above method has some advantage over piling.

There is no tendency to lamination in this perfectly homogeneous material, and its toughness and ductility are remarkably shown by the specimens exhibited, all of which have been twisted and bent while cold. Its tensile strength is upwards of 40 tons per square inch.

Cast steel rails are not an entire novelty; for several years ago a few were made at Ebbw Vale and were laid at the bridge at the north end of the Derby station, and there they are at the present time perfectly sound and good, whilst the neighbouring iron rails have been many times worn out and replaced. But these rails were made at a great expense from ingots cast in the old or usual method, and the imperfect appliances then existing made it impossible to introduce them commercially. Still the experiment at Ebbw Vale has clearly proved the far greater power of resisting wear and tear possessed by the steel rails; and now the method of producing ingots by the Bessemer process enables rails to be produced which bid fair to become in truth a really "permanent way."

Armour Plates.—In the further portion of the present paper, on the manufacture of Armour Plates, the writer's principal object is to elicit discussion upon this important subject; and as but a very short time has elapsed since the rival powers of the penetration of shot and the resistance of plates have been so seriously and energetically tested, it is necessary to speak with diffidence upon a matter which on all hands is allowed to be as yet imperfectly determined. No limit has yet been assigned to the magnitude of future artillery, nor has any degree of impenetrability of iron plates been declared unattainable. The manufacturer's business is simply to make the best and strongest armour which at the present time is wanted, and leave future possible requirements to be dealt with when the benefits of experience have been obtained. It does not come within the province of this paper to discuss the several questions involved in determining the best form of vessel to carry the weight of armour, nor to settle the resisting power of iron as compared with wood. The iron-maker's problem is how to produce the largest plate of iron of the maximum degree of toughness.

Two methods of producing large masses of wrought iron have been in use: the first by the process of building up under the steam hammer,

and the second by building up under the rolls. Under the steam hammer, the plate is produced by welding together lumps or masses of scrap iron, each mass of scrap being added and welded to the end of the plate, until it reaches the required length. Plates made in this way have been seriously objected to on account of their brittleness; and it is reasonable to suppose that this mode of manufacture is somewhat likely to induce brittleness. There can hardly be any continuity of fibre in a plate forged from masses of scrap iron, perhaps of different qualities, each at different heats; the nature of the weld and its form, and the repeated cooling and re-heating of the plate, are also adverse to its possessing great toughness. The rolled plates have been found more uniform in quality and of greater toughness than the hammered; and though the difficulties in their manufacture are grave, there is no departure from the ordinary practice followed in making large plates for other purposes. The difficulties which do exist are chiefly due to the immense weight and size and the intolerable heat of the mass, which must be dealt with while at a welding temperature.

The general size of the armour plates required for the plated frigates is from 15 to 18 feet long, from 2 feet 6 inches to 3 feet 10 inches wide, and $4\frac{1}{2}$ inches thick. The weight therefore of the finished plate ranges from 60 to 110 cwts.; and in the unfinished state it comes from the rolls at 80 to 140 cwts. From 3 to 4 inches is cut off the sides, and 10 or 12 inches from each end; and in this item of waste the hammering process has an advantage over the rolling.

The mode of manufacture of a 5 ton plate is as follows. Bars of iron are rolled 12 inches broad by 1 inch thick, and are sheared to 30 inches long. Five of these bars are piled and rolled down to a rough slab. Five other bars are rolled down to another rough slab, and these two slabs are then welded and rolled down to a plate of $1\frac{1}{4}$ inch thick, which is sheared to 4 feet square. Four plates like this are then piled and rolled down to one plate of 8 feet by 4 feet and $2\frac{1}{2}$ inches thick; and lastly, four of these are piled and rolled to form the final entire plate. There are thus welded up together 160 thicknesses of plate, each of which was originally 1 inch thick, to form the finished $4\frac{1}{2}$ inches, making a reduction of 35 times in thickness; and in this operation from 3500 to 4000 square feet of surface have to be

perfectly welded by the process of rolling. It is not surprising that even with the greatest care blisters and imperfect welds should exist and render the plate defective; this is the chief difficulty to be overcome, and a very serious one it is; and as the magnitude and weight of the plate increase so does also the liability to failure.

The final operation of welding the four plates of 8 feet by 4 feet by $2\frac{1}{2}$ inches is a very critical matter. To bring a pile of four plates of these dimensions up to a perfect welding heat all through the mass, without burning the edges and ends of the plates most exposed to the fire; to drag this pile out of the furnace, convey it to the rolls, and force it between them, in so short a time as to avoid its losing the welding heat, is a matter of greater difficulty than those unacquainted with the work would imagine. The intensity of the heat thrown off is almost unendurable, and the loss of a few moments in the conveyance of the pile from the furnace to the rolls is fatal to the success of the operation.

Figs, 1, 2, and 3, Plates 27, 28, and 29, show the arrangement of the armour plate mill at the writer's works. Fig. 1, Plate 27, is a general plan of that portion of the works: Fig. 2, Plate 28, is an enlarged plan of the heating furnace and rolls: and Fig. 3, Plate 29, an elevation of the furnace and rolls.

The pile of four plates A, Figs. 2 and 3, Plates 28 and 29, which united form the finished plate, is heated in a special furnace B, and is drawn out by a liberating chain attached to the roll on to an iron carriage C which conveys the pile to the rolls D. The carriage C travels upon a line of rails let into the ground; and close in front of the roll frame is a small incline E upon the railway, which lifts up the front of the carriage at the moment of its arrival at the rolls, and enables it to deliver the pile upon the fore-plate. As the plate passes through the rolls it is received on the other side upon a roller frame F, which is set at a considerable inclination towards the rolls, so that the tendency of the plate is to return. The rolls are then reversed; and the plate which was pressing against them passes back through, and is received upon the carriage C; and again the operation is repeated until the 10 inches thickness is reduced to $4\frac{1}{2}$ inches.

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The plate is then lifted off the carriage C by the crane G, and deposited upon a massive cast iron straightening bed H, and an iron cylinder I weighing 9 tons is rolled over it to and fro, being pinched along by hand levers, until the curvature which the plate has acquired in the rolling is entirely removed. As soon as the plate is sufficiently cool, it is lifted off the straightening bed H by another crane K, Fig. 1, Plate 27, and laid upon the planing machine L, where the final operation of planing its sides and ends is completed.

Mr. Brown exhibited specimens of the steel rails, fractured to show the quality of the metal; and pieces of the rails that had been bent double while cold without fracture: also a piece of 75 lbs. double headed rail which had been drawn down hot into a bar 1 inch square and then twisted cold without showing any tendency to cracking or splitting.

The Chairman enquired where the steel rails were laid, and how long they had been down, and what appeared to be their durability.

Mr. Brown said there were not many rails laid down at present in this country, and they had been used hitherto mainly on the continent; the longest had been down about six or seven months at the new Pimlico Railway Station in London, and had proved very satisfactory: they were answering admirably, and were in as good condition now as when laid down; and a set of steel points and crossings had also been in constant use for seven months at the same station. There were also some of the steel rails more recently laid on the Caledonian, Lancashire and Yorkshire, London and North Western, and Rhymney Railways, but these had not yet been down long enough to afford any results as to their durability.

The Chairman asked whether there had been any fractures of the rails in working, and what was the cost of them.

Mr. Brown replied there had not been any fractures in working, and the rails showed not the least brittleness but were much tougher than wrought iron rails. The fractured rails exhibited were purposely broken at the time of rolling to show the quality of metal; and its great toughness was proved by the bent and twisted rails exhibited, which were all done cold. The cost of the rails was of course higher than that of ordinary rails, and was an objection against them on the English railways; but continental companies were willing to pay the extra first cost of a more expensive rail, provided it would wear better than the ordinary rails, and he believed the steel rails would wear out at least five ordinary rails; but none of the steel rails had been used up yet, and their durability could therefore only be estimated from their comparative appearance after a short time of wear. The price of the rails was £18 10*s.* per ton in England, and £5 or £6 more on the continent.

Mr. Sampson Lloyd enquired whether the steel for the rails was made by the Bessemer process.

Mr. Brown replied that it was all Bessemer steel, and this process gave a great advantage in entirely getting over the difficulty and cost of producing such large masses of cast steel by the ordinary method.

Col. Kennedy enquired what reduction of weight it was considered could be safely made in the rails by the use of steel instead of the ordinary wrought iron rails.

Mr. Brown said the weight was reduced about one third as compared with ordinary wrought iron rails. The 75 lbs. double headed steel rails had been tested up to 80 tons in the centre with 3 feet length between the bearings, and the deflection was $2\frac{3}{4}$ or 3 inches without showing any signs of cracking.

Mr. J. Fenton asked how the 80 tons load was applied, whether by hydraulic pressure or by dead weights, and how it was measured; with hydraulic pressure it was sometimes difficult to ascertain the pressure correctly in measuring by safety valves. He enquired also whether the ends of the rails were fixed in the bearings during testing.

Mr. Brown said the load was applied by hydraulic pressure and measured by two safety valves, the valve of the press, and a separate valve on Mr. Naylor's plan fixed on purposely for the experiment, to

prevent any risk of mistake. The rails were simply supported on the bearings in testing, with the ends left free.

Col. Kennedy asked whether there was any buckling of the rail under the test load.

Mr. Brown said the rails did not buckle in the least, and the surface showed no signs of cracking with so heavy a test.

Mr. B. Fothergill enquired whether any change in the crystallisation of the steel rails took place after they had been in use for some time.

Mr. Brown replied that the rails laid in Pimlico Station had been well tested by exposure to severe work for six or seven months, and were as good as when laid, without any change being perceived.

Mr. R. Williams asked whether there was any difficulty in welding the steel rails.

Mr. Brown had not tried welding them, as each rail was rolled down to the required length from a single ingot of Bessemer steel of the proper size for making the entire rail.

The Chairman enquired in reference to the manufacture of the armour plates what was the quantity of work that could be done in rolling the plates, and how many were produced per day in regular work.

Mr. Brown replied that in ordinary work with the one mill now in operation 3 plates were turned out per day of 12 hours, weighing 5 or 6 tons each; if working all the 24 hours, 5 or perhaps 6 plates per day might be made, but this would require a second furnace for heating the plates, to allow of stopping and cleaning one furnace without delaying the work.

Mr. A. B. Cochrane asked whether the 3 plates per day were turned out with one furnace.

Mr. Brown said that number of plates was made with only the one furnace; but at present they lost two or three days in every fortnight when the furnace had to stand for repairs, and if a great quantity of plates were required two furnaces would be used, so as to keep the work going constantly.

Mr. R. Williams enquired whether the piling of the iron was the same for the armour plates as for rolling ordinary plates.

Mr. Brown replied that the piling was just the same, the only difference of the armour plates from ordinary plates being in the quality of the iron, as none but the best description of scrap was used in the pile.

Col. Kennedy enquired what experiments had been made on these armour plates to determine their power of resisting shot.

Mr. Brown replied that two trials of the plates had been made some time previously, but they were not satisfactory to the admiralty or themselves; these were however their first attempts in rolling the armour plates, and they did not expect to succeed at once without some failures. He showed specimens of the broken portions of the plates, from which it was seen that the failure arose from the imperfect welding of the four thicknesses composing the armour plate in the final heat.

Two armour plates however, subsequently tried at Portsmouth in the last fortnight, had proved much more successful. The plates were $4\frac{1}{2}$ inches thick, backed by 18 inches thickness of teak, and were fired at with shot 68 lbs. weight from a 95 cwts. smooth bore gun of 8 inches bore with 16 lbs. charge of powder at 200 yards range. The first plate, shown in Fig. 4, Plate 29, was 7 feet 9 inches long by 3 feet 2 inches wide: the first shot hit near a corner of the plate, at a place where the weld was imperfect, and indented the iron to some depth; the second shot also hit near the same place and indented the plate; the third shot struck the plate in the centre and made a hole right through the iron, making a crack all round the opening; the fourth shot hit near the bottom and broke the lower edge of the plate in; and the fifth shot happened to go through the hole made by the third. The second plate, shown in Fig. 5, Plate 29, was nearly double the length of the first, being 14 feet long by 3 feet 7 inches wide: the first shot indented the plate 3 inches and broke out the iron at the centre of the indentation; the second shot punched right through and broke the backing; and the third and fourth shots each broke out a hole of 12 inches diameter and smashed the backing. A portion broken off one of the plates was exhibited, which showed that the iron was much more fibrous than in the plates made in the first attempts; and he expected still more favourable results would be obtained if the iron

could be kept in a thoroughly fibrous state, so as to have a soft and tough quality, which was less easy to fracture than a hard and brittle metal.

Two of the armour plates were now in the hands of the admiralty for further experiments; and trials had just been made at Shoeburyness of two of the plates 5 inches thick, which had proved altogether most satisfactory as to the tenacity and toughness of the plates. The object was to produce armour plates capable of resisting guns of increased power, and the experiments now made seemed to show that this might be effectually accomplished by the mode of manufacture that had been described.

The Chairman observed that the quality of the plate could be better judged of when it had been actually pierced in the experiments than when only indented, as they could then see the character of the hole and examine minutely the completeness of welding of the several thicknesses. He enquired whether the Bessemer steel had been tried for the armour plates.

Mr. Brown had not yet tried it for the armour plates, but expected to do so shortly, when he had a hammer heavy enough for working it; he intended using a 4 ton Naylor's steam hammer, with the steam admitted above the top of the piston in the fall to increase the force of blow.

The Chairman remarked that he felt a great interest in the manufacture of the armour plates, as he was himself engaged on the other hand in endeavouring to increase the power of guns so as to penetrate the strongest plates that could be made. As regarded the mode of manufacturing the plates, he had seen and examined those which had been fractured in the experiments, and his own observations at present were unfavourable to rolling the several thicknesses together to form the plates, as not giving pressure enough to ensure a thorough welding in all parts. Moreover the extent of surface to be welded, amounting to 3000 or 4000 square feet in the entire manufacture of a single plate, was so great that it was difficult to conceive how a perfect weld could ever be obtained throughout, as it seemed impossible to ensure an entire exclusion of dirt from between the plates, and unless they were kept quite clean they could not be welded into a

single homogeneous plate. The difference in resisting power was very great between a really homogeneous material and one having any lamination of structure: in the latter case all portions of the material did not take their share of the strain in resisting a blow, but some were more severely strained than the rest, causing them to give way sooner; and a series of thinner plates though making up a considerably greater total thickness was inferior to a single homogeneous plate in resisting power. The very best plates he had seen at present were some small forged plates worked under a hammer at Portsmouth dockyard; these were thoroughly sound in all parts and free from impurities. What was wanted for the armour plates was a perfectly homogeneous material, and of soft texture; if they could be made like the steel rails that had been described, from a single mass of thoroughly homogeneous metal, he thought there might be a good prospect of success. Ordinary cast steel however he did not think would be so suitable as good wrought iron, on account of not being soft enough; for in all the trials he had made of cast steel for vent pieces of breech-loading guns he had found it a very unsatisfactory material, as it had no power of endurance, and though it would stand a great charge at first, it failed after continued use; and even though the firing was carried on with smaller charges than the proof charge, a point was at length arrived at when the fracture took place. He could not tell whether this tendency to fracture arose from a defect in the material, by its assuming gradually a crystalline character under repeated strains; or whether a small fracture was started at first by the highest charge and then went on gradually increasing at each successive trial until the metal gave way entirely.

For forging the metal of the armour plates under the hammer, he considered the weight of the hammer was of the greatest importance; and in reference to the use of a 4 ton hammer with steam above the piston to increase the blow, it had to be borne in mind that the steam increased only the velocity of the blow without adding to the mass falling, which was not the result required; he feared the effect would be that the force of the blow would be spent on the surface of the material and would not go through the centre of the mass like the blow of a heavier weight falling with a proportionately smaller

velocity. This appeared to him a very important consideration in forging large masses, however effective that kind of steam hammer undoubtedly was for lighter work.

He moved a vote of thanks to Mr. Brown, which was passed, for the interesting and valuable information given in his paper.

The following paper was then read :—

ON THE MANUFACTURE OF CAST STEEL AND ITS APPLICATION TO CONSTRUCTIVE PURPOSES.

By Mr. HENRY BESSEMER, of London.

The mode of manufacturing Cast Steel, which now forms so important a branch of the Sheffield trade, was discovered in the year 1740 by Mr. Benjamin Huntsman of Handsworth near Sheffield; who subsequently established steel works at Attercliffe, where his most valuable invention has ever since been successfully carried on. In its early stages many difficulties had doubtless to be overcome: materials for lining the furnaces and for making the crucibles had to be sought for and tested; the peculiar marks of iron most suitable for melting had to be determined on by numerous experimental trials; and such was the difficulty at that time of making crucibles which would stand the excessive heat of melted steel that for a long period only very highly carbonised or "double converted" steel, which required the lowest temperature, could be successfully melted. The first products of a new manufacture, even while the invention still remains in a partially developed state, but too frequently stamp its subsequent character. Thus Huntsman's cast steel, although it was acknowledged to be a pure homogeneous metal of great value for certain purposes, was still looked upon as a hard and brittle material of very limited use, not bearing a high temperature without falling to pieces, and quite incapable of being welded: even within the last few years this has been the popular idea of cast steel. Improvements in its manufacture have however from time to time been introduced; and steel of a milder and less brittle character has long been made, capable of welding with facility and working at a high temperature without falling to pieces. Its uses have consequently been greatly extended, and the employment of cast steel for the best cutlery and edge tools has now become universal; indeed the excellent quality of the cast steel at present made in Sheffield for these purposes is

scarcely to be surpassed. Of late years several of the most enterprising manufacturers have sought to introduce cast steel for a variety of other purposes besides those for which it was originally employed, and it is now used in some form or other in almost every first class machine. Its employment as a material for founding bells and various other articles in clay moulds, as carried out by Messrs. Naylor and Vickers, and the introduction of a valuable material by Messrs. Howell and Shortridge, under the name of homogeneous metal, are prominent examples of the successful adaptation of cast steel to engineering purposes.

The manufacture of cast steel by Huntsman's process is so extensively practised and is so well known that it is unnecessary to do more than recall to mind that crude pig iron has first to go through all the stages of melting, refining, puddling, hammering, and rolling, in order to produce a bar of malleable iron as nearly pure as the most careful manipulation in charcoal fires can make it. Bar iron, on which so much labour, fuel, and engine power have been expended, thus becomes the raw material of this most expensive manufacture. In order to convert the wrought iron bars into blister steel, they are packed with powdered charcoal in large firebrick chests, and are exposed to a white heat for several days; the time required for heating and cooling them extending over a period of 15 to 20 days. When thus converted into blister steel they are broken into small pieces and sorted according to the quality of the steel, which sometimes differs even in the same bar. For melting this material powerful air furnaces are employed, containing two crucibles, into each of which are put about 40 lbs. of the broken blistered steel. In about 3 hours the pots are removed from the furnaces, and the melted steel is poured into iron moulds and formed into ingots of cast steel, from 3½ to 4 tons of hard coke being consumed for each ton of metal thus melted. When large masses of steel are required, a great many crucibles must be got ready at the same moment, and a continuous stream of the melted metal from the several crucibles must be kept up until the ingot is completed, since any cessation of the pouring would entirely spoil it: hence in proportion to the size of the ingot are the cost and risk of its production increased. The ordinary manufacture of cast steel is

therefore obviously conducted at a great disadvantage. If cast steel is to supersede wrought iron for engineering purposes, it will be necessary to cease employing wrought iron as a raw material for this otherwise most expensive mode of manufacture.

The extremely high temperature requisite to maintain malleable iron in a state of fusion has from the earliest period of the history of iron down almost to the present day rendered its purification in a fluid state practically and commercially impossible. Hence arise all those imperfections to which bar iron is subject, every small piece consisting of numerous granules partially separated from each other by scoria, and every large mass being produced only by piling together small bars, with the inevitable result of increasing the former imperfections; for no two pieces of iron can be brought to a welding heat without becoming coated with oxide, and when this coating is rendered fluid by welding sand a fluid silicate of the oxide of iron is formed, covering the entire surface to be united. The heavy blows of the hammer or the pressure of the rolls may and do extrude the greater portion of this fluid extraneous matter, but it is never wholly removed from between the welded surfaces, and hence a portion of the cohesive force of the metal is lost at every such junction. When a bar of iron is nicked on one side and bent, the rending open of the pile clearly shows this want of perfect cohesion. Nor is this the only difficulty to be encountered; for in the production of large masses of wrought iron it is necessary to raise the temperature nearly to the fusing point, in order to render each additional piece sufficiently soft and plastic to become united to the bloom: this softening of the iron induces a molecular change in the structure of the metal; its natural tendency to crystallise is so powerfully assisted by the long continuance of the high temperature that its whole structure undergoes a change; large and well-defined crystals are formed almost independent of each other, and cohering so feebly to the other contiguous crystals as in some cases to separate with as little force as would overcome the cohesion of ordinary cast iron. In the substitution of cast steel for malleable iron, both these sources of difficulty are escaped; for the mass, whether of 1 ton or 20 tons weight may be formed in a fluid state into a single block, wholly free from admixture of scoria, while

it is perfectly and equally coherent at every part; and the forging of such a solid block of metal into shape is only the work of a few hours, and as there is no welding of separate pieces it may be worked under the hammer at a temperature at which no molecular change will take place, the metal being far below its fusing point and much too solid to undergo that destructive crystallisation so common in large masses of wrought iron. Thus the difficulties and uncertainty attending the production of all large masses of wrought iron are wholly avoided in producing equally large masses of cast steel.

But however desirable in the abstract it may be to employ cast steel as a substitute for malleable iron for engineering purposes, it must not be forgotten that there are several important conditions indispensable to its general use. Firstly, the steel must be able to bear a good white heat without falling to pieces under the hammer; otherwise the process of shaping it will not only be expensive, but the partly finished forging may be spoiled at any moment by being overheated. Secondly, the steel should be of such a tough character as to admit of being twisted or bent into almost any form in its cold state before fracture takes place, whether the force be applied as a gradual strain or by a sudden impact. Thirdly, it should have a tensile strength at least 50 per cent. greater than that of the best marks of English iron. Fourthly, it must especially be soft enough to turn well in the lathe, to bore easily, and to yield readily to the file and chisel, so as not to enhance its original cost by the difficulty of working it into the requisite forms. The last is both commercially and practically an important condition, and one which will in future greatly determine the extent of its use. Steel to the engineer has hitherto stood in much the same relation as granite to the builder: the superior hardness, beauty of polish, and durability of granite as compared with other building stone are universally acknowledged, nature has provided it in great profusion, and it has only to be lifted from the earth and made use of; but the practical man has found that to drill a hole in granite for blasting takes days of labour to accomplish, that the stone blunts all the chisels, defies the saw, and is faced only at a great cost; hence the builder goes on using an inferior soft stone over which the tools have perfect command. The

problem to be solved therefore is how to produce cast steel that will take any form in the mould or under the hammer, that will yield quickly and readily to all the present cutting and shaping machines, and will retain all the toughness of the best iron with a much greater tensile strength, and all the clearness of surface, beauty of finish, and durability that so eminently distinguish the harder and more refractory qualities of the steel in common use.

These desirable objects are believed by the author to be fully accomplished by his process of converting crude pig iron into cast steel at a single operation, forming the subject of the present paper. This process has now been in daily operation in Sheffield for the last two years. The apparatus by which it is effected is shown in Plates 30 to 33, which represent the arrangement at Messrs. John Brown and Co.'s, Atlas Steel Works, Sheffield: Fig. 1, Plate 30, is a side elevation, and Figs. 3 and 4, Plate 31, a front elevation and plan.

The crude pig iron chiefly used in this process has been the hot-blast hæmatite pig smelted with coke, which is melted in a reverberatory furnace adjoining, and is then run into the converting vessel A, Figs. 1 and 3, Plates 30 and 31, in which its conversion into steel is to be effected. The converting vessel is shown enlarged in section in Fig. 5, Plate 32, which represents its position in filling, the melted pig iron being run into it by the spout B direct from the furnace. It is made of stout boiler plate and lined with a powdered silicious stone found in the neighbourhood of Sheffield below the coal and known as "ganister." The rapid destruction of the lining of the converting vessel was one of the great difficulties met with in the early stages of the invention: the excessive temperature generated in the vessel together with the solvent action of the fluid slags was found to dissolve the best firebrick so rapidly that sometimes as much as 2 inches thickness would be lost from the lining of the vessel during the 30 minutes required to convert a single charge of iron into steel. The ganister now used however is not only much cheaper than firebricks, costing only about 11*s.* per ton in the powdered state, but it is also very durable: a portion of the lining of the vessel is shown which has stood 96 consecutive conversions before its removal. The converting

vessel A is mounted on bearings which rest on stout iron standards CC, Figs. 3 and 4, and by means of the gearing and handle D it may be turned into any required position. There is an opening at the top for filling and pouring out the metal; and at the bottom of the vessel are inserted seven fireclay tuyeres, Fig. 9, Plate 33, each having seven holes, as shown enlarged in the longitudinal section and plan, Figs. 10 and 11. The blast from the engine is conveyed through one of the bearings E of the vessel, Fig. 3, Plate 31, into the tuyere box F, and enters the tuyeres at a pressure of about 14 lbs. per square inch, which is more than sufficient to prevent the fluid metal from entering the tuyeres.

Before commencing with the first charge of metal, the interior of the converting vessel is thoroughly heated by coke, with a blast through the tuyeres to urge the fire; when sufficiently heated it is turned upside down and all the unburnt coke falls out. The vessel is then turned into the position shown in Fig. 5, Plate 32, and the melted pig iron is run in from the furnace by the spout B, the vessel being kept in such a position during the time it is being filled that the holes of the tuyeres are above the surface of the metal. When the proper charge of iron has been run in, the blast is turned on and the vessel quickly moved up into the position shown in Fig. 6. The blast now rushes upwards into the fluid metal from each of the 49 holes of the tuyeres, producing a most violent agitation of the whole mass. The silicium always present in greater or less quantities in pig iron is first attacked, and unites readily with the oxygen of the air, producing silicic acid: at the same time a small portion of the iron undergoes oxidation, and hence a fluid silicate of the oxide of iron is formed, a little carbon being simultaneously burnt off. The heat is thus gradually increased until nearly the whole of the silicium is oxidised, which generally takes place in about 12 minutes from the commencement of the process. The carbon of the pig iron now begins to unite more freely with the oxygen of the air, producing at first a small flame, which rapidly increases, and in about 3 minutes from its first appearance a most intense combustion is going on: the metal rises higher and higher in the vessel, sometimes occupying more than double its former space, and in this frothy fluid state it presents an enormous surface to the action

of the air, which unites rapidly with the carbon contained in the crude iron and produces a most intense combustion, the whole mass being in fact a perfect mixture of metal and fire. The carbon is now burnt off so rapidly as to produce a series of harmless explosions, throwing out the fluid slag in great quantities; while the combustion of the gases is so perfect that a voluminous white flame rushes from the mouth of the vessel, illuminating the whole building and indicating to the practised eye the precise condition of the metal inside. The blowing may thus be left off whenever the number of minutes from the commencement and the appearance of the flame indicate the required quality of metal. This is the mode preferred in working the process in Sweden. But at the works in Sheffield it is preferred to continue blowing the metal beyond this stage, until the flame suddenly drops, which it does just on the approach of the metal to the condition of malleable iron: a small measured quantity of charcoal pig iron containing a known proportion of carbon is then added, and thus steel is produced of any desired degree of carburation, the process having occupied about 28 minutes together from the commencement. The converting vessel is tipped forwards and the blast shut off for adding this small charge of pig iron, after which the blast is turned on again for a few seconds.

The vessel is then turned into the position shown in Fig. 7, Plate 33, and the fluid steel run into the casting ladle G, which is carried by the hydraulic crane H, being counterbalanced by the weight I on the opposite end of the jib. When all the metal is poured out of the converting vessel, the crane is raised by water pressure and turned round, as shown in Fig. 2, Plate 30, for the purpose of running the steel into the ingot moulds K. Instead of tilting the casting ladle for pouring into the mould, it is made with a hole in the bottom, fitted with a fireclay seating L, Fig. 8, Plate 33, and closed by a conical plug of fireclay M, forming a conical valve. The valve rod N is coated with loam and bent over at the top, and works in guides on the outside of the ladle, as shown in Fig. 7, with a handle O for opening and closing the valve. By thus tapping the metal from below, no scoria or other floating impurities are allowed to run into the mould, and the stream of fluid steel is dropped straight

down the centre of the mould right to the bottom, without coming in contact with the sides of the mould. The moulds are made of a slightly tapered form, as shown in Fig. 8, so that as the ingot contracts in cooling it liberates itself from the mould completely on all sides; and the mould is removed by being lifted off the ingot when sufficiently set. The moulds are arranged in the moulding pit in an arc of the circle described by the casting ladle, as shown in the plan, Fig. 4, Plate 31.

By this process from 1 to 10 tons of crude iron may be converted into cast steel in 30 minutes, without employing any fuel except that required for melting the pig iron and for the preliminary heating of the converting vessel, the process being effected entirely without manipulation. The loss on the weight of crude iron is from 14 to 18 per cent. with English iron worked in small quantities; but the result of working with a purer iron in Sweden has been carefully noted for two consecutive weeks, and the loss on the weight of fluid iron, tapped from the blast furnace was ascertained to be only $8\frac{3}{4}$ per cent. The largest sized apparatus at present erected is that in use at the Atlas Steel Works, Sheffield, as shown in the drawings already described, the converting vessel being capable of converting 4 tons at a time, which it converts into cast steel in 28 minutes. In consequence of the increased size of the converting vessel in this case no metal is thrown out during conversion: and the loss of weight has fallen as low as 10 per cent., including the loss in melting the pig iron in the reverberatory furnace.

Specimens of this manufacture as carried on at the author's works in Sheffield are exhibited, consisting of a piece of the pig iron employed, which is No. 1 hot-blast hæmatite made with coke; also a portion of an ingot of very mild cast steel, broken under the hammer to show the purity and soundness of the metal in its cast unhammered state; and an ingot partly forged to show how little work with the hammer will produce a forging from those solid blooms of steel. There are also two pieces of steel of the quality employed for making piston rods, which have been bent cold under a heavy steam hammer to show the toughness of the metal: it requires very

much more force to bend it than would be required to bend wrought iron, but notwithstanding this additional rigidity it yields to any extent without snapping. The tensile strength of this soft and easily wrought metal is as much as 40 tons per square inch, or from 15 to 18 tons greater than that of best Yorkshire iron. In turning, planing, boring, and tapping, it will be found that the uniformity of its quality will be less trying to the cutting tools than the hard reeds and sand cracks met with in the common qualities of malleable iron. The above tensile strength of the piston-rod steel however is by no means the maximum, but on the contrary is nearly the minimum strength of the steel converted by this process; but at the same time it possesses nearly a maximum degree of toughness, for every additional ton in tensile strength obtained by the addition of carbon hardens the steel for working, renders it more difficult to forge, and brings it nearer to that undesirable state when a sudden blow snaps it like a piece of cast iron.

The extreme limits of tensile strength of the converted metal are shown in the following tables, which give the results of many trials made at different times at the Royal Arsenal at Woolwich under the superintendence of Colonel Wilmot:—

BESSEMER STEEL.

Tensile Strength per square inch.

Bessemer Steel.	Various trials.	Mean Tensile Strength.
In the cast unhammered state.	Lbs. 42,780 48,892 57,295 61,667 64,015 72,503 77,808 79,223	63,023 lbs. = 28·13 tons per square inch.
After hammering or rolling.	136,490 145,512 146,676 156,862 158,899 162,970 162,974	152,912 lbs. = 68·26 tons per square inch.

V

BESSEMER IRON.

Tensile Strength per square inch.

Bessemer Iron.	Various trials.	Mean Tensile Strength.
In the cast unhammered state.	Lbs. 38,197 40,234 41,584 42,908 43,290	41,243 lbs. = 18·41 tons per square inch.
After hammering or rolling.	64,059 65,253 75,598 76,195 82,110	72,643 lbs. = 32·43 tons per square inch.
Flat Ingot rolled into Boiler Plate without piling.	63,591 63,688 72,896 73,103	68,319 lbs. = 30·50 tons per square inch.

From these tables it is seen that, after hammering or rolling, the steel or highly carbonised metal exhibits a mean tensile strength of 68 tons per square inch, but from its hardness and unyielding nature it is totally unfit for many purposes; while the iron or entirely decarbonised metal is so soft and copper-like in its texture as to yield to a mean tensile strain of 32 tons per square inch, a point unnecessarily low except in cases where a metal approaching copper in softness is required. The soft easy-working tough metal of the quality used for piston rods is therefore believed by the author to be the most appropriate material for general purposes, while the hard steels that range up to a tensile strain of 50 or 60 tons per square inch should be avoided as altogether too expensive to work and too dangerous to be employed in any case where sudden strains may be brought upon them.

With reference to the employment of the mild cast steel for constructive purposes, there are few applications of more importance than that which has recently and successfully been made to the construction of steam boilers. The Cornish boiler, as improved by Mr. Adamson of Hyde near Manchester, has a large flue tube constructed

with narrow plates more than 12 feet long, extending round the flue in one length, and flanged at each edge in a manner which, while it adds greatly to the stability of the flue, demands such qualities in the material employed for its manufacture as are completely found only in metal that has undergone fusion and has become perfectly homogeneous throughout. A practical illustration of the excellence of this mode of constructing boilers and the powerful strains which the new steel is capable of sustaining safely is afforded by the steam boilers employed for some time past at Messrs. Platt's works at Oldham, where six of these boilers are in daily use; they are 30 feet long and $6\frac{1}{2}$ feet diameter, and the flue is 4 feet diameter; the plates are $\frac{5}{16}$ inch thick, and the working pressure 100 lbs. per square inch.

The advantages of cast steel are still more marked in the construction of the fireboxes of locomotive engines. The difficulty of flanging and shaping this work in plate iron without splitting the metal at some part is so great as to have rendered the employment of copper necessary hitherto for this purpose; but the shape required can now be obtained with ease and certainty by hammering up a sheet of metal rolled from one of the cast ingots, such as that now exhibited. One of these firebox plates flanged by Mr. Adamson is also shown, and clearly illustrates the facility with which the new metal may under skilful hands be wrought into any required form. The perfect continuity of the material and its entire freedom from joinings or weldings also obviously render it specially suitable for the tube plates of locomotive engines; for however near the holes are made to one another, there is no danger of their having a flaw or other weak place between them. This is exemplified in the piece of plate now exhibited, in which rivet holes have been punched so close as to remove almost all the metal, without splitting the narrow piece still left between the holes. Nor is it in the construction of the boiler alone that the cast steel may be employed with advantage in locomotives: the axles whether plain or cranked, the piston rods and guide bars, and last but not least the wheel tyres, are all exposed to so much abrasion and to such sudden and powerful strains that a tough strong material capable of withstanding this destructive wear and tear is imperatively

demanded for the satisfactory construction and economical working of the engine.

The special aim of the author during the first year of his labours, which throughout the last six years has never been lost sight of, was the production of a malleable metal peculiarly suitable for the manufacture of ordnance. By means of the process that has been described solid blocks of malleable cast steel may be made of any required size from 1 to 20 or 30 tons weight, with a degree of rapidity and cheapness previously unknown. The metal can also with the utmost facility be made of any amount of carburation and tensile strength that may be found most desirable: commencing at the top of the scale with a quality of steel that is too hard to bore and too brittle to use for ordnance, it can with ease and certainty be made to pass from that degree of hardness by almost imperceptible gradations downwards towards malleable iron, becoming at every stage of decarburation more easy to work and more and more tough and pliable, until it becomes at last pure decarbonised iron, possessing a copper-like degree of toughness not found in any iron produced by puddling. Between these extremes of temper the metal most suitable for ordnance must be found; and all qualities are equally cheap and easy of production.

From the practice now acquired in forging cast steel ordnance at the author's works in Sheffield it has been found that the most satisfactory results are obtained with metal of the same soft description as that employed for making piston rods. With this degree of toughness the bursting of the gun becomes almost impossible, its power of resisting a tensile strain being at least 15 tons per square inch greater than that of the best English bar iron. Every gun before leaving the works has a piece cut off the end, which is roughly forged into a bar of 2 inches by 3 inches section, and bent cold under the hammer in order to show the state of the metal after forging. Several test bars cut from the ends of guns recently forged are exhibited.

The power of this metal to resist a sudden and powerful strain is well illustrated by the piece of gun muzzle now shown, which is one of several tubular pieces that were subjected to a sudden crushing

force at the Royal Arsenal, Woolwich, under the direction of Colonel Wilmot; the pieces were laid on the anvil block in a perfectly cold state, and were crushed flat by the falling of the steam hammer, but none of them exhibited any signs of fracture when so tested. Probably the best proof of the power of the metal to resist a sudden violent strain was afforded by some experiments made at Liége by order of the Belgian government, who had one of these guns bored for a 12 lbs. spherical shot of $4\frac{3}{4}$ inches diameter, and made so thin as to weigh only $9\frac{1}{4}$ cwts. This gun was fired with increasing charges of powder and an additional shot after each three discharges, until it reached a maximum of $6\frac{3}{4}$ lbs. of powder and eight shots of 12 lbs. each or 96 lbs. of shot, the shots being thus equal to about one-tenth of the weight of the gun. It stood this heavy charge twice and then gave way at about 40 inches from the muzzle, probably owing to the jamming of the shots. The employment of guns so excessively light and charges so extremely heavy would of course never be attempted in practice.

Some idea of the facility of this mode of making cast steel ordnance is afforded by the time occupied in the fabrication of the 18-pounder gun now exhibited, which was made in the author's presence for his experiments on gunnery. The melted pig iron was tapped from the reverberatory furnace at 11.20 A.M., and converted into cast steel in 30 minutes; the ingot was cast in an iron mould 16 inches square by 4 feet long, and was forged while still hot from the casting operation. By this mode of treating the ingots their central parts are sufficiently soft to receive the full effect of the hammer. At 7 P.M. the forging was completed and the gun ready for the boring mill.

The erection of the necessary apparatus for the production of steel by this process, on a scale capable of converting from crude iron enough steel to make forty of such gun blocks per day, will not exceed a cost of £5000, including the blast engine; hence the author cannot but feel that his labours in this direction have been crowned with entire success: the great rapidity of production, the cheapness of the material, and its strength and durability, all adapt it for the construction of every species of ordnance.

For the practical engineer enough has already been said to show how important is the application of cast steel to constructive purposes, and how this valuable material may be both cast and forged with such facility and at a cost so moderate as to produce by its superior durability and extreme lightness an economy in its use as compared with iron. The construction of cast steel girders and bridges, and of marine engine shafts, cranks, screw propellers, anchors, and railway wheels, are all deserving of careful attention. The manufacturer of cast steel has only to produce at a moderate cost the various qualities of steel required for constructive purposes to ensure its rapid introduction; for as certainly as the age of iron superseded that of bronze, so will the age of steel succeed that of iron.

Mr. Bessemer exhibited an 18-pounder gun made of the Bessemer steel cast in a single ingot of the required size and subsequently hammered, with a variety of specimens of the metal, broken to show the quality of the fracture; also some piston rods, a boiler plate flanged for a locomotive firebox, and a plate bulged in a die without cracking or tearing, a plate of thin metal punched with a number of small holes very close together, and a tube of metal which had been crushed flat without the surface of the metal cracking. He showed also one of the fireclay tuyeres used for blowing the melted metal in the converting vessel, and specimens of the ganister used for lining the vessel and ladle, both new and after use.

The Chairman enquired whether the steel produced by this method was considered superior in quality and regularity of make as compared with that made by the ordinary process of conversion, apart from the question of cost of manufacture.

Mr. Bessemer said that from all the experiences they had had of the steel there was certainly no inferiority in quality when made from the best qualities of iron; no process had yet succeeded in making best steel from very common iron, and all steel makers resorted to

good iron for making the best steel, which he expected would long continue a necessary condition of success. The custom of the Sheffield steel makers was to use none but best Swedish iron or other foreign iron of high character for making all the best cast steel; and the same result was obtained with at least equal success by the new process from the same material. But in addition to this he had also succeeded in producing from lower qualities of English iron a very valuable material having great regularity of make and possessing important advantages in the combination of toughness and strength; while the cost was so much below that of any previous cast steel as to bring it into use in place of wrought iron for many purposes from which steel was entirely excluded hitherto by the high cost. For the best steel he still made use of Swedish pig, as the purest and best iron; but the process had this great advantage over the ordinary method of making steel, that in the latter the steel was produced by converting bars of wrought iron made from .the original pig, but in the new process the pig itself from which the bars would have been made was treated direct, thus saving the entire cost and waste of the intermediate process of manufacturing the iron into bars. Hence taking the same brand of pig iron, an equally good quality of steel was obtained at a greatly reduced cost, and with greater uniformity of conversion than was possible by the ordinary process of cementation, since the metal was dealt with in a liquid state, instead of in the form of solid bars which could be acted upon from the outside only. He expected in time to be able to obtain a still better result from the lower qualities of English iron, as there was nothing in the process itself to prevent any description of iron from being converted into the best steel that it was capable of yielding.

In the new process the carbon and silicium of the iron itself were employed as fuel to support the heat for reducing the cast iron, and the intense heat thus obtained together with the intimate mixing of the air blown through the metal while in a fluid state caused the reduction to be much more rapid. Instead of the silicium in the iron requiring 2 or 3 hours to be burnt out, as in the ordinary puddling process, it was now burnt out in only 12 minutes, giving out a great amount of heat by its combustion; and the complete reduction of the

metal occupied less than half an hour, and was accomplished with far greater certainty and completeness, while 3 or 4 tons were acted upon at once, instead of only as many cwts.

For the construction of ordnance an excessive toughness of metal was wanted, and in this respect the new steel had an advantage over ordinary cast steel which rendered it specially suitable for that purpose. Toughness implied a soft and mild quality of steel, but this required a very high temperature for melting, and it was not enough for the metal to be simply fluid, but it must be what the workmen called *well* melted; for if merely brought to a state of fusion and then formed into an ingot it did not work satisfactorily in the subsequent process of forging. In the ordinary process the difficulty of getting the steel sufficiently well melted increased in proportion to the softness or mildness of the metal: hence it sometimes occurred that a manufacturer would not attempt using quite so mild a quality of steel for a large casting; and a little more hardness was allowed, so as to admit of a lower temperature for melting, by increasing the extent of carbonisation in order to render the operation of casting less troublesome and expensive. But in the new process any degree of softness could be allowed, and the reduction in the converting vessel could be carried on till the metal even approached malleable iron, without adding at all to the trouble or expense of casting. When the reduction was carried to the extreme extent, the metal had a remarkably tough and soft quality, like copper, and seemed likely to prove a very valuable material for many purposes where these properties were of importance. The most satisfactory material for making guns he believed would be a perfectly homogeneous metal, having somewhat of the character of steel, but closely approaching malleable iron, of a tough quality and without any weldings; and this mode of casting the gun in a single large ingot of the required size, as shown in the specimen exhibited, precluded the possibility of working up improper material into the gun, and ensured its possessing the same strength in all parts.

The Chairman enquired whether the plates made from the new steel were much used at present, such as the specimens of flanged boiler plates that were exhibited.

Mr. Bessemer replied that the plates were now extensively in use and the steel proved a very good material for boiler plates, as it was very reliable in working from being of such a uniform texture throughout.

Mr. D. Adamson said he had already used 200 tons of boiler plates made from the new steel and was about to procure a further supply of 70 tons; he found the metal of excellent quality and regular character throughout, and it was an admirable material for working. The flanged firebox plate now shown was a duplicate of a number that he had used in the manufacture of boilers for very high pressure with most satisfactory results; the metal flanged beautifully and was like copper in this respect, but with the advantage that it was not so liable as copper to be damaged by heating. He could fully confirm the statements given as to its strength, having tested it very severely: as a precaution every plate had been ordered with 1 inch margin all round, which was then sheared off and bent double as a test of the quality of the plate; it was found to stand this test well, and bent double like the specimens exhibited without cracking at any part of the surface. The price of the plates was an important consideration in making steel boilers for the advanced pressures now coming into use; the boilers that he had made with the new plates cost about one third more than with best iron plates, but then the joints were all double riveted, and a large portion of the rivet holes drilled instead of punched, to obtain greater accuracy of work and avoid straining the metal, the boilers being intended for working at high pressures of 100 lbs. per square inch and upwards. The increased cost was therefore mainly occasioned by the superior workmanship; but it was well worth while to bestow a higher class of labour upon the higher class of metal here produced, whereby a far more valuable result was obtained. The durability of these steel plates in the fire flues of steam boilers with hard firing had been well tested in some boilers he had made for Messrs. Platt at Oldham, the results of which had been thoroughly satisfactory.

The only difficulty he had met with in working the new steel arose from unequal expansion of the plates or bars, when they had left the rolls at different temperatures. When a plate that had left the rolls

at a low temperature was riveted to one that had not been rolled so cold, the two did not expand equally when exposed to a considerable heat in the working of the boiler, and there was a constant strain on the joint; this difficulty gave some trouble at first, but was now got over by having all the plates and bars annealed for some time, after leaving the rolls, and they were then thoroughly soft and uniform in quality, so that they could be worked in any way with the greatest facility.

In resisting the strain of compression to which the internal flues of boilers were exposed, there was no doubt the steel plates would be much stronger and better than ordinary boiler plates; he had not however made much diminution of thickness in the metal, preferring to take full advantage of the increased strength in that part of the boiler; but it was very desirable that experiments should be made to determine the actual strength of the new plates in such positions. Whether the plates would withstand a tensile strain equally well in all directions he thought should also be tried; as in the case of the attachment of the domes of steam boilers, where the bottom of the dome was flanged out for riveting to the boiler, and the metal at that part was subjected to two strains at right angles to each other, one of them tending to tear the plate asunder from the edge inwards. It was therefore important to try whether the plates would stand such a compound strain as well as they resisted the single bursting strain in the barrel of a boiler; for if this were the case, they might be depended upon with equal security for all situations. They were essentially superior he considered to any plates manufactured from piled iron, as they were entirely free from lamination and were truly homogeneous throughout.

Mr. W. Richardson said he had made a trial of the Bessemer steel plates for some time in boilers at Messrs. Platt's works at Oldham, where some years ago a higher pressure of steam was adopted than was then usual. At that time they frequently found distress at the joints of the boilers, and had then adopted double riveting; and the firebox plates were frequently blistered, though of a good make of iron. Subsequently three boilers were made of plates of homogeneous metal, which had now been at work three years; but since the

Bessemer steel had been produced at a cheaper rate and equally reliable in strength and quality they had used it extensively, and had now six boilers constructed of the new plates. They had now no more trouble from blistered plates and strained joints, while a great saving was effected in thickness of metal, requiring less fuel to produce the same heating power: the steel plates were only $\frac{5}{16}$ inch thick for the same strength as the former $\frac{9}{16}$ inch iron plates, so that there was only $\frac{5}{8}$ inch thickness at the lap of the joints instead of $1\frac{1}{8}$ inch, or only $\frac{1}{16}$ inch greater thickness at the joints of the steel plates than with the single thickness of ordinary iron plate. They had had only two years' experience of the new plates at present, but during that time the results had proved thoroughly satisfactory.

Mr. B. Fothergill asked whether the Bessemer plates showed any liability to become corroded along the line of the joints where the plates overlapped, as was frequently the case in wrought iron boilers, which were liable to become cracked at that part to a considerable depth in the thickness of the metal, in consequence of the plates trying to pull themselves straight on both sides the joint when the pressure was on, and recovering themselves again each time the steam was down.

Mr. W. Richardson said he had not observed any corrosion yet in the steel plates, but the boilers had not been long enough at work to prove whether they would remain free from it. Their own practice was to strip all the boilers once a year for a thorough examination, and clean out all the scale and dirt, and then put on a coat of linseed oil all over, which was very effective in preserving the plates from corrosion. The boilers were $6\frac{1}{2}$ feet diameter, and 30 feet long, with one fire flue 3 feet 10 inches diameter, and worked at a pressure of 85 lbs. per square inch.

Mr. H. W. Harman enquired whether in the process of manufacturing the steel any other means had been arrived at of ascertaining the quality of the metal in the converting vessel and its degree of preparation, beyond merely observing the appearance of the flame from the mouth of the vessel and its cessation when the conversion was completed: and whether the indications were sufficiently accurate to ensure the same quality of metal being produced at all times.

Mr. Bessemer replied that the new process afforded great facility for judging of the quality of metal in the converting vessel, more so than any other process for manufacturing steel. For the quality was determined not only by the judgment of the workmen, who after some practice could tell with great accuracy from the changes in the flame; but the time of blowing into the converting vessel was definitely measured according to the weight of metal it contained, and the small quantity of pig iron added in the last stage of the process was also accurately weighed, thus determining the exact quantity of carbon put into the metal to convert it back from wrought iron into steel, which had not been so definitely accomplished in any previous method of conversion. As the process was entirely mechanical and independent of the workmen, the result could be relied on with great certainty; it was thus very different from the ordinary case of puddling in the manufacture of wrought iron, where the quality of iron produced depended altogether on the judgment and skill of the workman. The sudden drop in the flame when the decarbonisation of the iron was completed could be observed with great readiness; and the measured weight of melted pig iron containing a known proportion of carbon was then added at once, combining with the metal while in a melted state, and producing a definite quality of steel. With 20 cwts. of metal in the crucible 120 lbs. of pig iron was the usual quantity added, which was increased up to 130 or 140 lbs. for making harder qualities of steel. The uniform and soft quality of the steel that had been rolled into boiler plates was shown by the severe manner in which it had been tested, by cutting off a strip from every plate for trying; but a further test was afforded by the subsequent working of the plate, for if it were brittle and irregular, hard in some places and soft in others, that would inevitably be found out in punching and flanging. The use of the large quantity of the plates already employed at the works where they were so tested was a satisfactory proof of the uniform quality of steel obtained by the new process.

With regard to corrosion of the steel plates in boilers, in no case was steel dissolved by acid so much as wrought iron. The new steel especially, being a perfectly homogeneous material united closely

at all points and entirely free from lamination of structure, presented no inequalities of texture and no openings for the corrosion to begin eating its way in: whereas iron had innumerable small fissures in its substance, and if the surface of any malleable iron were filed or planed smooth, and then covered with a dilute acid for a few minutes, on wiping off the acid an etching was left all over the surface from the irregularity of the material, capable even of being printed from; but on the steel plates no such effect was produced by the acid. This showed how wrought iron became corroded, by the corrosion commencing in the minute interstices at its surface and gradually extending itself through them into the body of the iron. The bars of wrought iron pallisades were known to become corroded at the bottom in this way; and even cast iron suffered in a similar manner, though in a much smaller degree.

Mr. H. Maudslay observed that an interesting point had been elicited in the discussion, with regard to the different expansion of the new steel plates when they had left the rolls at different temperatures. He thought that further information and experiments on the subject were highly desirable, and as to whether the remark applied to the new steel alone or to iron generally.

Mr. D. Adamson had tried three sets of bars, of Bessemer steel, puddled steel, and scrap iron, that had left the rolls at different temperatures, the bars all 10 feet long and each set welded together at one end: after heating them to a moderate red heat there was found to be as much as $\frac{1}{8}$ inch difference in length among the rods of the same material, and he therefore came to the conclusion that it was not advisable to unite together in the same work plates that had left the rolls at different temperatures, as the coldest rolled plates expanded more on being reheated the first time. However on reheating the same rods, not one tenth of the difference first observed took place; and the objection at first experienced was now obviated by annealing all the plates and bars of Bessemer steel for some hours after they had left the rolls.

Mr. H. Maudslay thought that the effect of the second heating was very remarkable, in causing the difference of expansion to disappear: it showed the necessity of having all bars or plates of the new steel

left in a known state after rolling, by annealing them as described, in order to avoid the inconvenience of variable expansion.

The CHAIRMAN said the specimens of metal exhibited and the results obtained were certainly highly satisfactory, and the new process appeared one of great scientific beauty. If the new steel could indeed be produced regularly of the quality described and in large masses, it was the very material that had long been wanted by engineers. He only wondered it was not more in use at present, if these results were permanently secured and could be fully relied upon in regular manufacture.

The use of steel plates for boilers had been tried for some time, but he believed the objection to them had been want of uniformity in temper and quality, so that they could not be used with safety. But if the new process was so successful in excluding all liability to variation of quality and in producing a really homogeneous steel, an equal strength in all parts of the plates might be relied on; and he was glad to hear now of their being practically applied for boiler purposes.

There was not so much difficulty however in the case of plates worked down under rolls in obtaining sufficient strength and soundness of work; the great difficulty was with a great thickness of metal, in ensuring soundness in the interior of large castings and equal density and toughness in all parts. The new process did not appear exempt from this difficulty, which applied to a homogeneous metal when worked in large masses almost as much as to ordinary iron; and there seemed to be no short road to making large forgings, but they must still go through a sufficient amount of heavy hammering to ensure the necessary solidity. For such work one essential he was satisfied was a massive forge hammer, greatly enlarged beyond those at present in general use. Mr. Krupp of Essen in Prussia, who had been the pioneer in the treatment of cast steel in large masses, was now actually erecting an enormous hammer of 40 tons weight; and this must be in order to get over some objection experienced where the steel was not sufficiently hammered. In his own experiments on the manufacture of ordnance he had tried all sorts of steel, excepting the Bessemer steel, when the greatest pains had been taken by the makers

to overcome the difficulties and produce a thoroughly sound material. But nearly all the trouble in connexion with guns had arisen from using steel, and he had not been able to get any steel to stand the action of long continued firing. In a bar where the thickness was small it had tenacity enough, but in a block it was different, the liability to fracture displaying itself as soon as any considerable thickness was attempted. It was quite possible however that if well worked under a large hammer while hot, a large mass of steel might be made to have all the good qualities that it possessed when worked on a small scale. He enquired whether any gun of large mass had been attempted with the new steel.

Mr. Bessemer replied that he had not yet made any guns larger than the 18 pounder now exhibited, excepting a few 24 pounders; but the 12 pounder spherical-shot gun of the new steel, tried in Belgium, was bored to $4\frac{3}{4}$ inches diameter, which was the same diameter of bore as that of the Armstrong 40 pounder guns, while the weight was only $9\frac{1}{4}$ cwts. as compared with 34 cwts. the weight of the old cast iron guns of the same bore, and 32 cwts. the weight of an Armstrong 40 pounder. The great strength obtained with so light a gun was well shown by the experiments in Belgium with the 12 pounder gun of the new steel, the metal of which was only $1\frac{3}{8}$ inch thick at the muzzle and $2\frac{3}{8}$ inches at the breech; but it stood the test of firing with continually increasing charges, from 2 shots of 12 lbs. each and $2\frac{1}{4}$ lbs. of powder, up to 8 shots or 96 lbs. of shot and $6\frac{3}{4}$ lbs. of powder. At the third firing of this heavy charge the gun parted at about the middle of its length, where the thickness of metal was $1\frac{7}{8}$ inch, probably on account of the shot slightly overriding one another and getting jammed at the muzzle; at the same time the excessive recoil of the gun under so large a charge tended to snap the metal asunder, but there was no rupture of the gun longitudinally.

He fully acknowledged the great labours of Mr. Krupp of Essen, who was undoubtedly the leader in the production of large masses of cast steel; but he thought the large 40 ton steam hammer that had been mentioned was intended only for the very largest work, such as engine shafts of 20 or 30 tons weight, and the general run of work would not require hammers larger than the ordinary size at present used.

The great advantage of using cast steel for making large pieces of work was that there were no welds in the mass of metal, but it was cast at once of the full size required and of nearly homogeneous quality throughout, and was then beaten out under the hammer into the proper shape, having been cast originally in the form most suitable for producing the finished forging. The old practice with cast steel was to let the ingot get cold after casting, and it was left to lie rusting before being worked into shape, under a mistaken notion of its becoming milder by exposure in the air. But the gun now exhibited of the new steel was never allowed to get cold from the time of casting till the forging was finished. The metal was poured from the ladle into a cold iron mould, forming an ingot 16 inches square and 40 inches long; the external surface got cooled directly, but the inside remained still so soft that a rod could be run down the centre when the outside was cold enough to be solid. After remaining 20 minutes in the cold mould it was then too cold outside for working under the hammer, though still very hot inside; and it was therefore put in a furnace for a short time and reheated on the outside till it was nearly equally hot all through, leaving still however an excess of heat in the centre. The inside was protected from damage in the reheating by being completely encased in the cooler exterior portion, and got no injury, not being exposed to the air; but when put under the hammer the centre was so much softer than the outside that the large masses thus cast in the mould could be readily hammered through right to the centre. The whole forging was thus completed at the only time when the mass was in the very best condition for working, for in no subsequent reheating could it ever be got hotter in the centre than on the outside, nor even so hot; but in ordinary forging, the entire heating being done from the outside which was exposed to the atmosphere, the metal was unavoidably overheated on the outside and more or less burnt, whilst the interior was still not sufficiently heated for the blow to penetrate the mass fully.

Toughness and tensile strength did not require a laminated structure of the metal, but depended on softness of quality and on the amount of hammering it had undergone. In trials he had made of the effect of hammering on the new steel, an ingot just cast,

3 inches square, sustained a tensile strain of 21 tons per square inch, but after being reduced $\frac{1}{4}$ inch each way by hammering it stood 57 tons per square inch; on further drawing it down however to a bar $\frac{1}{2}$ inch square, no more practical gain in strength was obtained, showing that a certain moderate amount of hammering, if properly done, produced the full effect that was required in condensing the substance of the metal. The object of the hammer was not to weld the steel together, as in hammering a bloom of wrought iron, but merely to compress the particles together, and the crystals then united most readily; nor was the hammering needed to develop a fibrous character in the metal, for fibre had nothing to do with the strength of steel, but an ingot simply condensed by a small amount of hammering after casting possessed the same strength as if drawn down into a bar under the hammer.

Mr. R. Longsdon thought the circumstance that the new steel had not yet been brought into more extensive use could not be taken as an argument against its value; for the difficulties of introducing any new material were so great, and in the ordnance experiments it was admitted the steel had not even had a trial at present. That more had not already been done was no reason why more should not yet be done, when the new steel had become better known. Hitherto it had been used mainly for comparatively small articles, but these had proved thoroughly successful, and he thought that in large forgings there was no doubt of the same success being obtained when the steel was sufficiently hammered after casting.

The Chairman gathered from the statements made about the new steel that it did not differ materially from cast steel obtained by the ordinary process, except in being much less expensive and more truly a homogeneous and pure metal. From his own experience of ordinary cast steel he was not able to speak favourably of it for large masses of metal such as guns: but he was sure all would be glad if the difficulties connected with it could be overcome, and all would most heartily wish success to Mr. Bessemer's ingenuity and perseverance.

He proposed a vote of thanks to Mr. Bessemer for his highly interesting paper, which was passed.

The following paper was then read:—

ON THE STRENGTH OF STEEL CONTAINING DIFFERENT PROPORTIONS OF CARBON.

By Mr. T. EDWARD VICKERS, of Sheffield.

Three most important materials of British manufacture—wrought iron, steel, and cast iron—are combinations of iron with a smaller or larger amount of carbon. Wrought iron contains from about $\frac{1}{8}$ to $\frac{1}{2}$ per cent. of carbon, cast steel about $\frac{3}{8}$ to 2 per cent., and cast iron from $2\frac{1}{2}$ to 7 per cent. The great variety of opinions that have been expressed respecting the strength of steel when containing different proportions of carbon led the writer to make a number of tests upon this point, the results of which are given in the present paper with the conclusions derived from them.

The degree of carbonisation in the several varieties of steel tested in the experiments ranged from about $\frac{1}{3}$ per cent. of carbon to $1\frac{1}{4}$ per cent.; the softest or least carbonised steel containing $\frac{1}{3}$ per cent. of carbon was called No. 2, and the hardest or most highly carbonised containing $1\frac{1}{4}$ per cent. of carbon No. 20, the intermediate numbers representing intermediate degrees of carbonisation. The tests to which the steel was subjected consisted in ascertaining its tensile strength, by means of bars of the steel broken by direct tension; and also its transverse strength, by means of axles made of the steel which were broken by the blows of a heavy ram.

Tensile Strength.—The tensile strength of the several varieties of steel was tested by the simple lever machine shown in Plate 34, in which the leverage is 220 inches to 11 inches, or 20 to 1, Fig. 1, so that each cwt. added in the scale at the long end of the lever produces a tension of 1 ton on the test bar at the other end of the lever. The test bars A, Figs. 2, 3, and 4, are $21\frac{1}{2}$ inches long, with 14 inches of their length turned down to a uniform diameter of 1 inch. For

facility of fixing the bars in the testing machine and removing them when broken, the ends are made wedge-shaped, and the lower end is held in a conical socket in the holding-down block B, into which it is inserted through the longitudinal slot shown in the plan, Fig. 6; the bar is then turned half round, and the upper end slipped into the wedge-shaped holder C at top, whereby the bar is securely held during the testing. The following Table I gives the results of the trials, showing the breaking strain reduced to tons per square inch, together with the amount of elongation produced in the bars:—

TABLE I.

Tensile Strength of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate).*	Breaking Strain per square inch.	Elongation.
	Per cent.	Tons.	Inch.
No. 2	0·33	30·4	1·37
No. 4	0·43	34·0	1·37
No. 5	0·48	37·5	1·25
No. 6	0·53	42·5	1·12
No. 7	0·58	41·5**	0·81
No. 8	0·63	45·0	1·00
No. 10	0·74	45·5	0·69
No. 12	0·84	55·0	1·12
No. 15	1·00	60·0	1·00
No. 20	1·25	69·0	0·62

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

** There was a flaw in this test bar, which will account for its breaking at a lower strain than the preceding No.

The elongation was measured after each addition of load in the scale at the long end of the lever; and that given in the table is the final amount of elongation, previous to adding the last cwt. in the scale which caused the breakage.

The table shows that the tensile strength of the steel is increased by the addition of carbon, until it is combined with about $1\frac{1}{4}$ per cent. of carbon, when it sustains about 69 tons per square inch. But

beyond this degree of carbonisation the steel becomes gradually weaker, until it reaches the form of cast iron, which sustains a tensile strain of only about 6 or $6\frac{1}{2}$ tons per square inch. When the test bar is turned down at one point only, instead of through a considerable length, the result obtained has been found to be different: for a bar of steel turned down to $\frac{3}{4}$ inch diameter at one point only, as shown at D in Fig. 5, did not break till the strain reached $79\frac{1}{2}$ tons per square inch; whereas a bar of the same steel turned down to 1 inch diameter for 14 inches of its length broke with a tension of 60 tons per square inch.

Transverse Strength.—For testing the transverse strength of the several varieties of steel, axles were made of the steel in the various degrees of carbonisation, which were subjected to the blows of a heavy ram until broken. The axles were all turned to 3·94 inches diameter at the centre and 4·25 inches at the ends, and were supported on bearings 3 feet apart, as shown in Figs. 7 and 10, Plate 35; they were reversed at intervals when considerably bent by the blows of the ram, as shown by Figs. 8 and 9. The ram weighed 1547 lbs. or nearly 14 cwts., and was dropped on the centre of the axle from a height commencing at 1 foot and increasing at each successive blow up to 36 feet fall, unless the axle was broken at a previous blow.

Table II gives the detail of the experiment on an axle of No. 4 steel containing about $\frac{4}{10}$ per cent. of carbon; showing that it stood 5 blows of the ram falling from 36 feet height before breaking, after 12 blows from lower heights of fall, and the sum of all the deflections produced by the blows amounted to 56 inches.

TABLE II.

Detail of Experiment on Transverse Strength of Axle made of No. 4 Steel.

No. of Blow.	Height of Fall.	Deflection.		
		Before blow.	After blow.	Effect of blow.
	Feet.	Inches.	Inches.	Inches.
1	1	— 0·00	⌣ 0·19	0·19
2	2	⌣ 0·19	⌣ 0·53	0·34
3	3	⌣ 0·53	⌣ 1·12	0·59
4	4	⌢ 1·12	— 0·00	1·12
5	5	— 0·00	⌣ 1·19	1·19
6	7½	⌣ 1·19	⌣ 2·19	1·00
7	10	⌢ 2·19	— 0·00	2·19
8	12½	— 0·00	⌣ 2·19	2·19
9	15	⌢ 2·19	⌣ 0·75	2·94
10	20	⌢ 0·75	⌣ 3·00	3·75
11	25	⌢ 3·00	⌣ 1·50	4·50
12	30	⌢ 1·50	⌣ 3·81	5·31
13	36	⌢ 3·81	⌣ 2·37	6·19
14	36	⌢ 2·37	⌣ 3·75	6·12
15	36	⌢ 3·75	⌣ 2·31	6·06
16	36	⌢ 2·31	⌣ 3·88	6·19
17	36	⌢ 3·88	⌣ 2·25	6·13
18	36	⌢ 2·25	broken	...
			Sum of Deflections	56·00

Table III gives the general results of the series of experiments made in a similar manner to the above, with axles of the several varieties of steel; showing the total number of blows required to break each axle, the number that it sustained with 36 feet fall of the ram before breaking, and the sum of all the deflections produced. Three wrought iron axles were also tried in the same way, one of the best faggotted axles that could be procured, and two scrap iron axles.

TABLE III.

Transverse Strength of Axles made of Steel containing different proportions of Carbon.

Material of Axle.	Proportion of Carbon (approximate).*	Total number of Blows.	Height of Fall in last blow.	Number of blows sustained from 36 feet height.	Sum of Deflections.
	Per cent.		Feet.		Inches.
Steel No. 2	0·33	17	36	4	58·81
No. 4	0·43	18	36	5	56·00
No. 5	0·48	18	36	5	53·56
No. 6	0·53	15	36	2	35·06
No. 7	0·58	16	36	3	38·81
No. 8	0·63	18	36	5	46·00
No. 10	0·74	16	36	3	40·31
No. 12	0·84	10	20	0	8·56
No. 15	1·00	8	12½	0	4·31
No. 20	1·25	10	20	0	6·94
Best wrought iron	...	13**	36	0	31·19
Scrap iron	...	5	5	0	2·00
Scrap iron	...	5†	5	0	3·69

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

** Cracks began to show at the tenth blow, with 20 feet height of fall, and increased at each subsequent blow.

† Two large cracks opened at the fifth blow, therefore it was considered practically broken.

From these experiments it appears that, for bearing sudden and heavy blows, without regard to rigidity, the metal cannot contain too little carbon, provided it be pure and there be perfect cohesion of the particles. These qualities however cannot exist to the required degree in wrought iron or puddled steel, as shown by the experiment with the wrought iron axle in the above table; and are to be found only in cast steel, which must contain at least enough carbon to render it sufficiently fluid in melting. The steel melting process alone can effectually rid the metal of the impurities that were contained in the iron from which it is made.

There is nothing more deleterious to iron or steel than overheating or too many heatings, and the writer believes that all welding affects the quality of the metal more or less injuriously. Cast steel has the great advantage of being less liable than any other metal in general use to become crystallised by vibration. It has already a natural crystal, and the result of the writer's experience is that its crystal can be changed into a weak form only by being overheated. Cast steel and Swedish wrought iron have been placed where they were subjected equally to continual blows, concussions, and vibrations; and the cast steel was found to stand for a long period without change of crystal, where the Swedish iron broke very soon, showing great changes in its form of crystallisation.

For most mechanical purposes the best material in practice is one that combines the power of resisting a tolerably high tensile as well as transverse strain; one that will bear a tension of about 45 to 50 tons per square inch will generally be quite strong enough, and will be below the point at which brittleness from too great rigidity begins. The following Table IV gives a comparison of the preceding Tables I and III, and shows that such a material is found in the steel Nos. 8 to 10, containing about $\frac{5}{8}$ to $\frac{3}{4}$ per cent. of carbon. There are of course purposes where a specially ductile or specially rigid material should be employed, but the latter should be used only in cases where it is not liable to be subjected to sudden concussions.

TABLE IV.

Transverse and Tensile Strength of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate).*	TRANSVERSE.	TENSILE.	
		Sum of Deflections.	Breaking Strain per square inch.	Elongation.
	Per cent.	Inches.	Tons.	Inch.
No. 2	0·33	58·81	30·4	1·37
No. 4	0·43	56·00	34·0	1·37
No. 5	0·48	53·56	37·5	1·25
No. 6	0·53	35·06	42·5	1·12
No. 7	0·58	38·81	41·5	0·81
No. 8	0·63	46·00	45·0	1·00
No. 10	0·74	40·31	45·5	0·69
No. 12	0·84	8·56	55·0	1·12
No. 15	1·00	4·31	60·0	1·00
No. 20	1·25	6·94	69·0	0·62

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

The superior strength of cast steel cannot be better illustrated than by stating that castings of steel, without hammering, rolling, or other means of mechanical compression, show a very high degree of strength and tenacity, far above that of castings of any other metal in practical use. Advantage is taken of this property to make bells of cast steel, one third lighter than bronze bells of the same diameter; and these lighter steel bells still bear double the breaking strain of the bronze ones. Another feature in the superior strength of castings in steel is that they are not so liable as other metals to break when subjected to concussions during intense frost, as proved by the fact that the cast steel bells have been rung without the least injury in Russia and in Canada, when the thermometer ranged lower than 20° below zero Fahr.; while the heavier and thicker bronze bells could not be rung in the same temperature without cracking.

The same properties have also led to the manufacture of cast steel disc wheels with tyres in one solid body, for railway carriages and engines. One of these disc wheels was tested in the manner shown

in Fig. 11, Plate 35: the wheel was put upon an axle fixed firmly in bearings at each end, and the ball E weighing 830 lbs. or nearly $7\frac{1}{2}$ cwts., suspended by an iron rod 24 feet long, as shown in the drawing, was drawn back and let fall so as to strike the wheel on the outside of the rim or tyre. The wheel was struck nine blows increasing from 1 foot to 14 feet in vertical height of fall, after which the axle was so much bent that the ball could not strike the wheel. The axle was then straightened by striking the wheel on the opposite side, and was propped up to prevent bending again; and two more blows were struck from the height of 15 and 16 feet, without causing any damage to the wheel.

The results of all the experiments that have been described show that cast steel, which even to the present time is considered by many a brittle material, fit only for a cutting instrument, is in fact a metal having not only all the good and desirable properties of wrought iron in a higher degree, but at the same time freedom from most of the objectionable properties of the latter, and admitting of being employed for every mechanical purpose where great ductility, tenacity, and transverse strength, are required.

In reference to the specific gravity of steel as affected by the proportion of carbon it contains, chemists and scientific writers have generally given the specific gravity of steel as about 7·850 and of wrought iron about 7·650, that of water being 1·000; which leads to the inference that the addition of carbon to iron has the effect of increasing its density, and such is the general opinion at present. The contrary however has been found by the writer to be the fact, namely that pure iron decreases in density the more carbon there is combined with it. The low specific gravity of wrought iron above stated must therefore have been obtained from common English merchant iron, a piece of which gave a specific gravity of 7·644, which very nearly agrees with that above mentioned; and must be owing to the impurities contained in the iron. The specific gravity of one of the purest and softest Swedish irons is 7·894; and that of the iron from which the steel was made for all the experiments that have been described above is about 7·860. Table V gives the specific

gravities as ascertained by experiment of the successive gradations of steel, from No. 2 containing about $\frac{1}{3}$ per cent. of carbon up to No. 20 containing about $1\frac{1}{4}$ per cent., the results having been all obtained with pieces of metal of considerable size, varying from $2\frac{3}{4}$ to $4\frac{1}{2}$ oz. in weight.

TABLE V.

Specific Gravity of Steel containing different proportions of Carbon.

Description of Steel.	Proportion of Carbon (approximate).*	Specific Gravity.
	Per cent.	
Swedish Iron, pure and soft	...	7·894
Iron from which the Steel was made	...	7·860
Steel No. 2	0·33	7·871
No. 4	0·43	7·867
No. 5	0·48	7·855
No. 6	0·53	7·855
No. 7	0·58	7·852
No. 8	0·63	7·848
No. 10	0·74	7 847
No. 12	0·84	7·840
No. 15	1·00	7·836
No. 20	1·25	7·823
Puddled Steel, for melting purposes	...	7·824
Cast Iron, mean of best authorities	$2\frac{1}{2}$ to 7	7·204

* The intermediate figures in this column, from No. 4 to No. 15 inclusive, are merely approximate, being interpolated in proportion to the numbers of the steel.

The specific gravities of the steel No. 2 and No. 4 are here seen to be greater than that of the original iron; but this may be attributed to the iron being freed from impurities in the melting. The conclusion therefore derived from the above figures is that every successive addition of carbon to pure iron renders the metal less dense or diminishes its specific gravity.

Mr. Vickers exhibited a number of strips of steel plate $\frac{5}{16}$ inch thick, which had been tested to show how far they could each be bent before cracking, when containing different proportions of carbon. Also a large cast steel pinion, and one of the steel axles that had been tested. After testing the axles, he had rolled down the broken pieces into plates $\frac{5}{16}$ inch thick, and tried them by bending, as shown by the other specimens exhibited. The softest steel, called No. 2 in the tables of experiments, had a tensile strength of only 30 tons per square inch, but the test plate made of it bore bending double without cracking, showing a great degree of toughness; while the most highly carbonised quality, No. 20, had the greatest tensile strength, amounting to 69 tons per square inch, but was so brittle that it snapped asunder without bending more than about 45° out of the straight line, as shown by the specimen exhibited. For the experiments on axles, in order to obtain the most correct results from wrought iron axles for comparison with those of steel, he got the best wrought iron axle he could of the regular faggotted make from a railway company, and also two scrap axles from makers who knew they were going to be tested; but the last two turned out worse than had been expected, and much inferior to the first, as seen from the table of experiments.

One circumstance to be noticed respecting the mode of testing the tensile strength of bars was that the results obtained with long test bars were different from those given by short ones. In a number of experiments upon this point he had found it to be regularly the case that if the test bar were turned down to the required diameter at one point only of its length it would stand one third more strain than if turned down to the same diameter throughout a length of 14 inches, This was a fact of much importance, as affecting the value of many experiments.

Mr. H. Maudslay observed that in turning down a long length of the test bar each part of that length was subjected to the strain, and therefore the test was exposed to all the chances of weak places occurring from irregularity in make of the bar at any point of its length; but when the bar was turned down at one part only, the chance of breaking at a weak place was confined to that small length only.

Mr. Vickers thought the result could not be merely an average of chances, for he had noticed that the bar was always stronger when turned down at one point only, in the manner described. He thought it might arise from the strain producing a greater effect in stretching the bar and reducing its diameter when turned down of uniform diameter for a long length, since steel always stretched considerably before breaking. The breakage occurred however at various points in the length turned down, not at the centre only.

The Chairman enquired whether the steel axles were in use on any railways.

Mr. Vickers replied that steel axles were used almost universally on the German railways, and also steel tyres and wheels. A number of the steel axles of the make now shown were in use there, and some of the cast steel wheels. Very few steel axles had yet been tried in England, but many steel tyres were now used.

Mr. R. Williams observed that the number of blows sustained by the axles from the maximum height in the experiments represented only a small portion of their strength, since the axle was rendered much weaker by being reversed between each blow.

Mr. B. Fothergill asked what amount of heating took place in the axle during testing, and whether any means were taken to cool it between the blows. In some experiments upon the fracture of axles he had found the heating considerable, and thought it was not a fair test to continue the blows when the axle had got hot, since its strength would then be affected.

Mr. Vickers did not think the heat in these experiments had been of any importance, as the testing of each axle occupied 2 or 3 hours, on account of the time taken up in raising the weight between each blow; and the axle lost its heat so rapidly during the interval as never to require cooling.

Col. Kennedy enquired what was the elastic strength of the different qualities of steel, or the limit to which they could be stretched without taking a permanent set. He thought it was of more importance to know this than the ultimate breaking strength.

Mr. Vickers said he had not ascertained the elastic limit of the steel in the experiments.

Mr. E. Riley asked what iron the steel was made from, and how far it was free from carbon in its original state previous to being converted into steel.

Mr. Vickers said the iron used was Swedish iron, which he had tested previously and believed to be as free from carbon as possible.

Mr. E. Riley doubted the freedom of the iron from carbon, and believed a small quantity of carbon was essential in wrought iron, without which it was useless. From experiments he had made he had found that the best wrought iron after being melted was always red-short and would not work at all, but was useless as wrought iron; and considered this was due to its being deprived of the small percentage of carbon it contained by the scale on its surface and the air in the melting pot. He had also found experimentally that fused wrought iron from the best ores was red-short and useless when made by reducing them with too small an amount of carbon, so as to leave oxide of iron in the cinder, which prevented any carbon from combining with the iron. This defect however was easily remedied by adding carburet of manganese, which supplied the requisite amount of carbon; and moreover the oxide of manganese produced acted also as a useful flux in separating some of the impurities contained in the iron: the addition of 1 per cent. of carburet of manganese to fused wrought iron made the iron work well, and prevented its being red-short.

The Chairman knew no question of so much importance to engineers as the effect of carbon on iron and steel, since the various qualities of both depended mainly on the proportion of carbon combined with them. A haze of doubt still hung over the subject, and called for further investigations to clear it away; but the period was now dawning when iron could be used in the form of mild cast steel, and an age of steel appeared likely to supersede that of iron. Tabulated experiments giving definite results, such as those in the paper, were the most efficient means of solving the question; and such information placed in the hands of engineers was of special value in enabling them to draw their own conclusions from the results obtained.

He moved a vote of thanks to Mr. Vickers for his paper, which was passed.

The Meeting was then adjourned to the next day.

In the afternoon the Members visited the works of Messrs. Naylor Vickers and Co., where the process of casting a large steel crank axle was shown, the steel for which was melted in 70 pots and poured into a casting ladle fixed above the mould, whence it was run into the mould by lifting a plug in the bottom of the ladle. One of the solid cast steel disc wheels which had previously been tested as described at the meeting was broken to show the soundness and quality of the steel; and a number of the cast steel bells were also exhibited and rung.

The Members then visited the works of Messrs. John Brown and Co., to see the rolling of the armour plates; and the plates that had been fractured in the experiments described at the meeting were shown. At these works also, and at those of Messrs. Bessemer and Co., the Bessemer process of manufacturing cast steel by direct conversion from crude pig iron was seen in operation; and a number of specimens were shown of the rails and boiler plates &c. made from the steel.

A number of the principal manufacturing establishments in the town and neighbourhood were also opened to the inspection of the Members.

The Adjourned Meeting of the Members was held in the Music Hall, Surrey Street, Sheffield, on Thursday, 1st August, 1861; Sir William G. Armstrong, President, in the Chair.

The following paper was read:—

ARMOUR PLATES.

Fig. 1. *General Plan of Armour Plate Mill.*

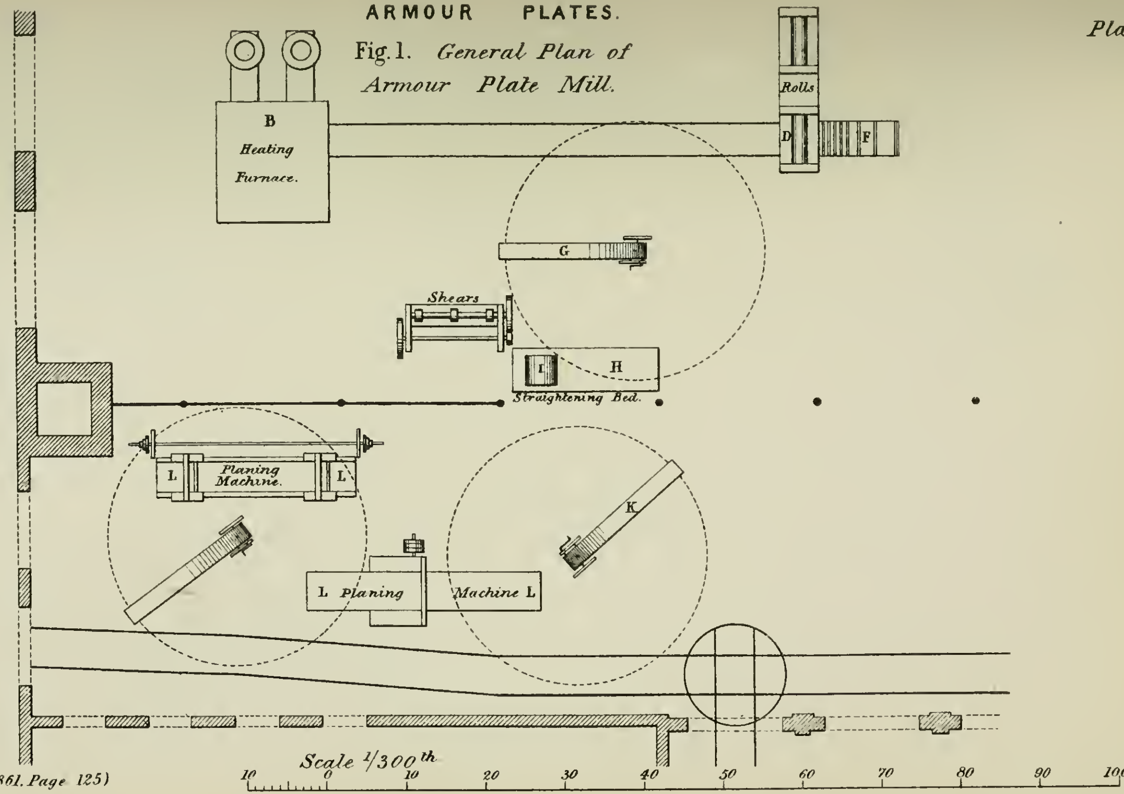


Plate 27.

ARMOUR PLATES.

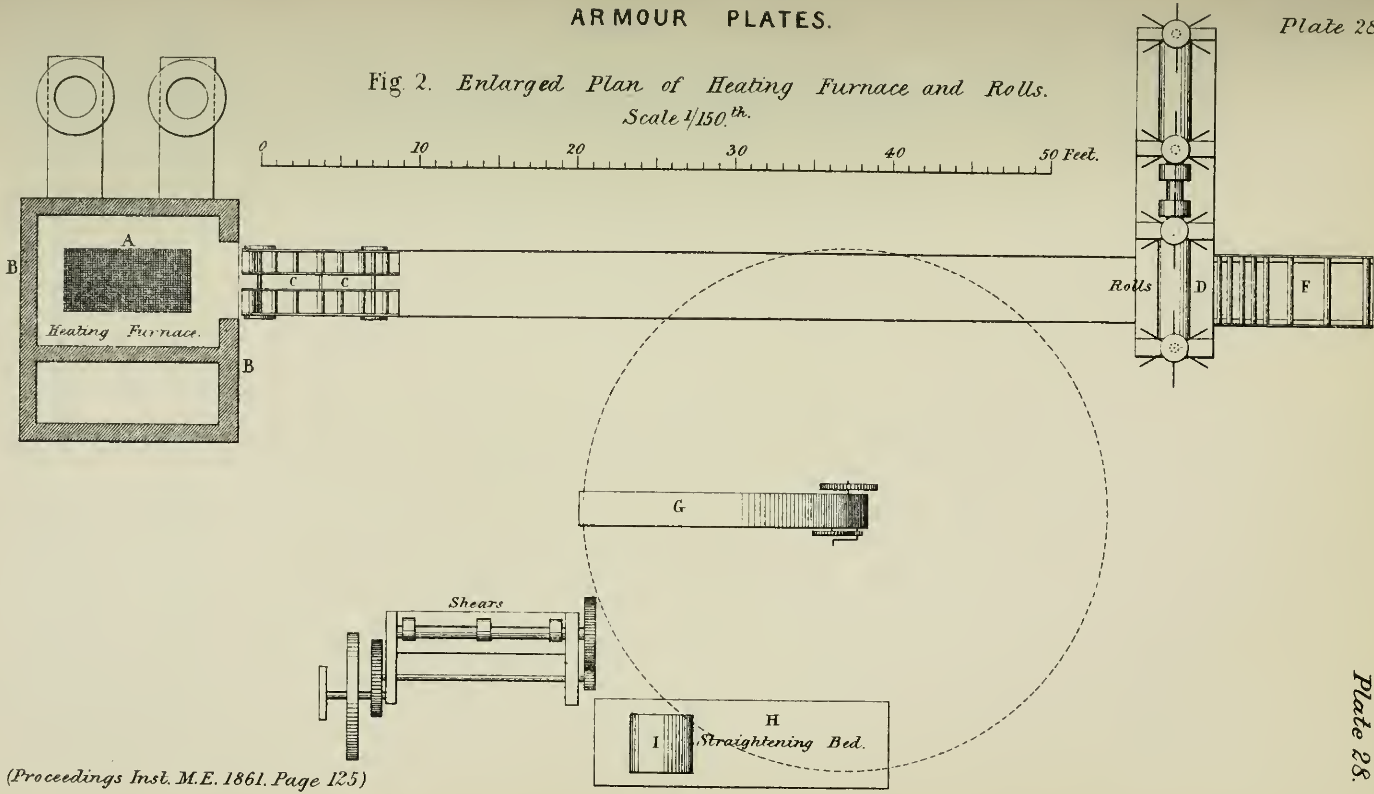


Fig. 2. *Enlarged Plan of Heating Furnace and Rolls.*
Scale 1/150.th

(Proceedings Inst. M.E. 1861. Page 125)

Plate 28.

ARMOUR PLATES.

Armour Plates tried in experiments.
Scale 1/50th.

Fig. 4.

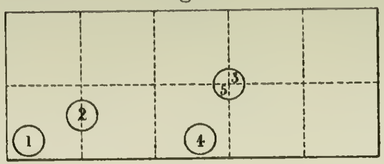


Fig. 5.

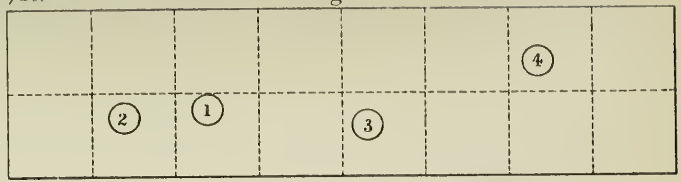
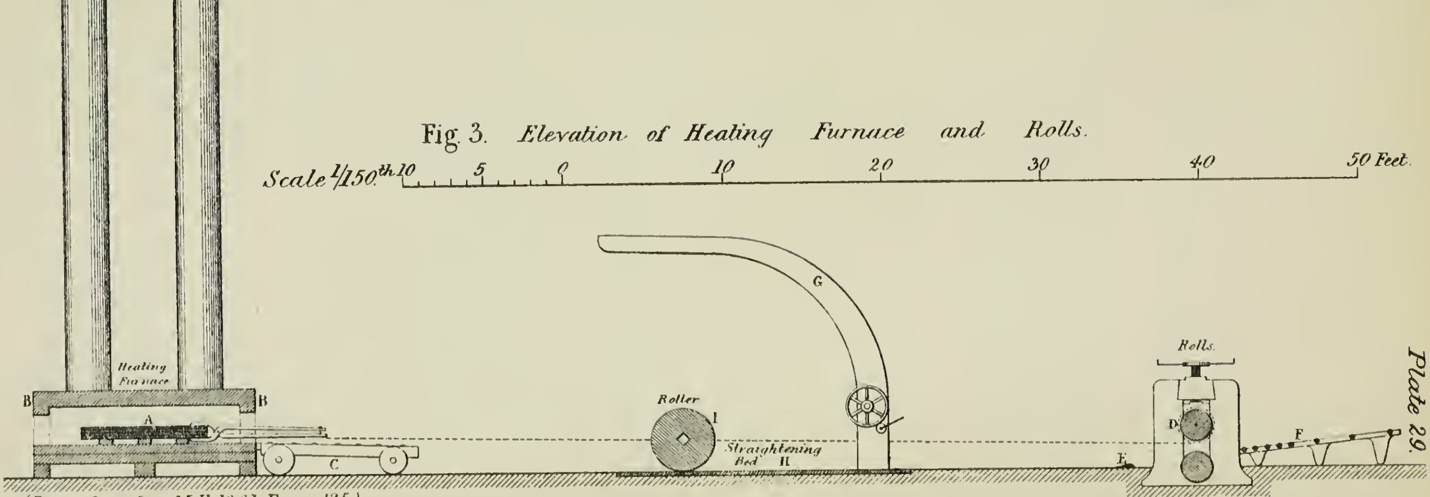


Fig. 3. *Elevation of Heating Furnace and Rolls.*



(Proceedings Inst. M.E. 1861. Page 125)

Fig 1. *Side Elevation of Converting Vessel, Casting Ladle, and Crane.*

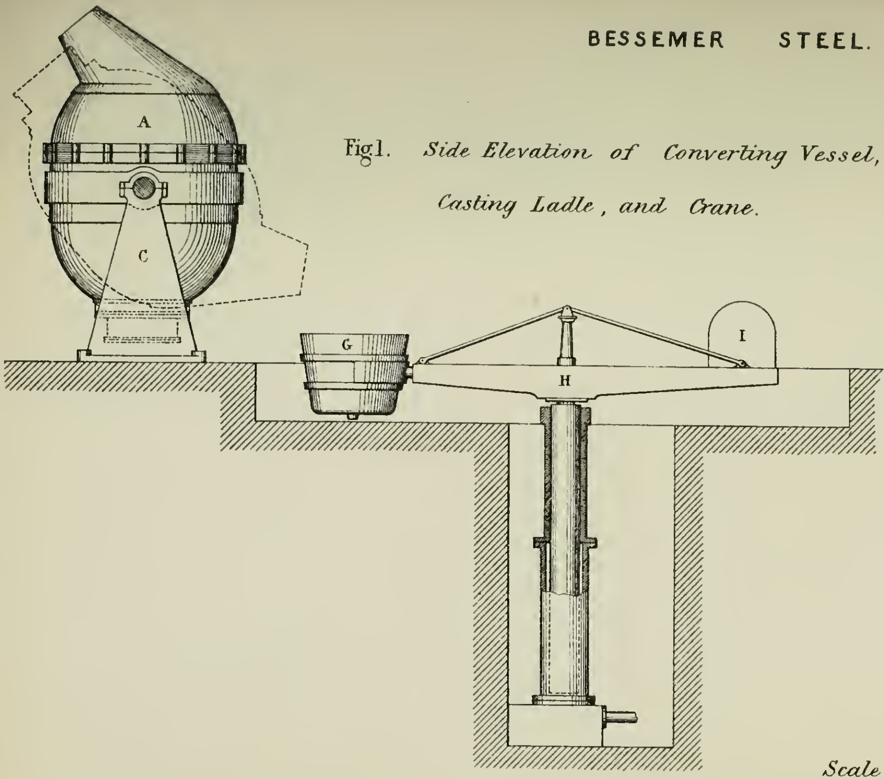
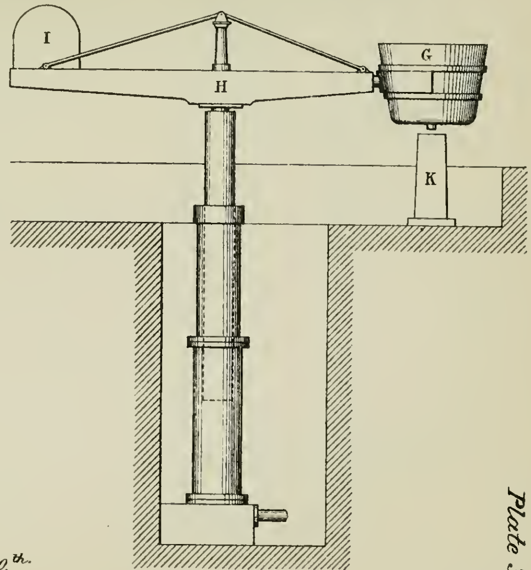


Fig. 2. *Casting the Steel into Ingots.*



Scale 1/80th.

0 10 20 30 Feet

Plate 30.

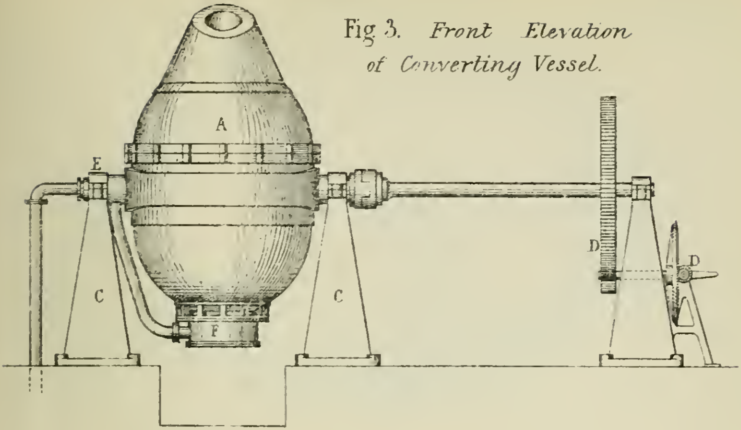


Fig 3. *Front Elevation of Converting Vessel.*

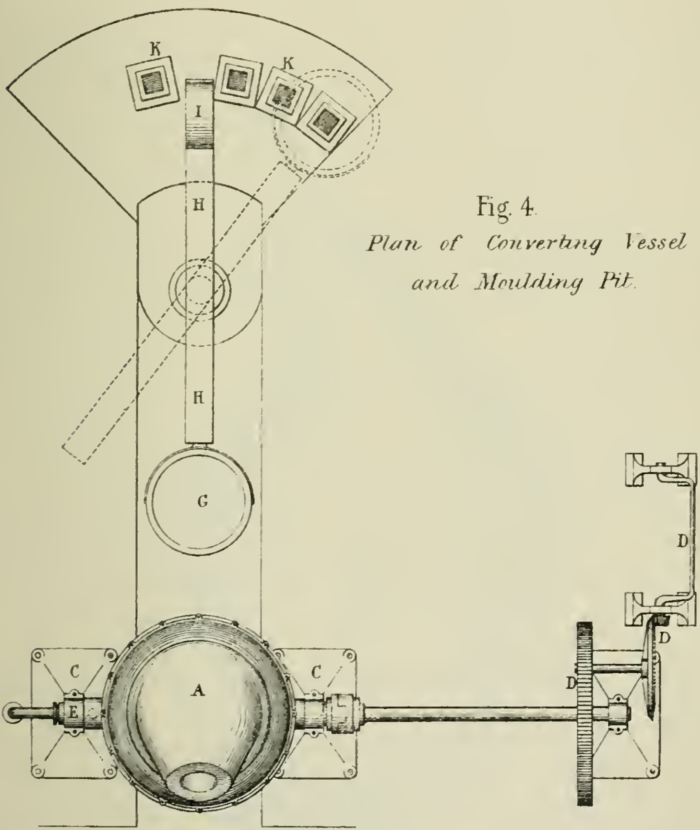


Fig. 4. *Plan of Converting Vessel and Moulding Pit.*

Scale 1/80th 0 5 10 15 20 *Feet.*

(Proceedings Inst. M.E. 1861. Page 133.)

BESSEMER STEEL.

Positions of Converting Vessel in filling and blowing.

Fig. 5. *Filling.*

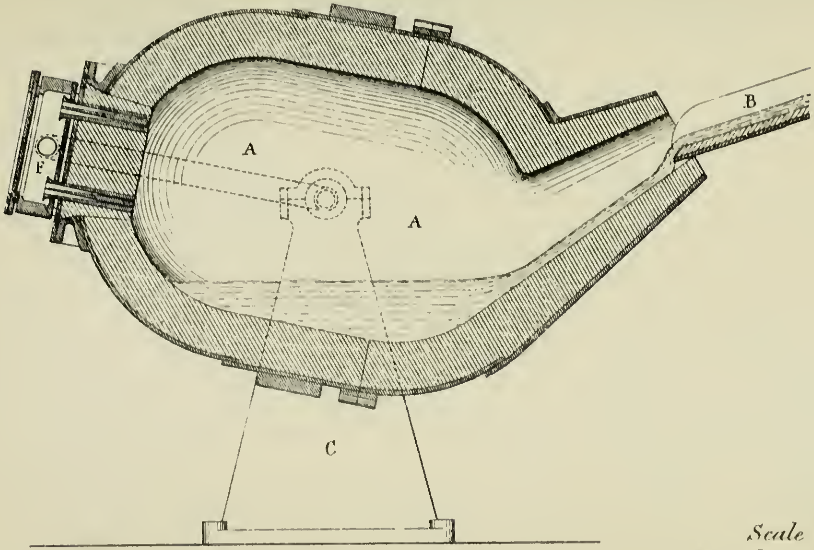
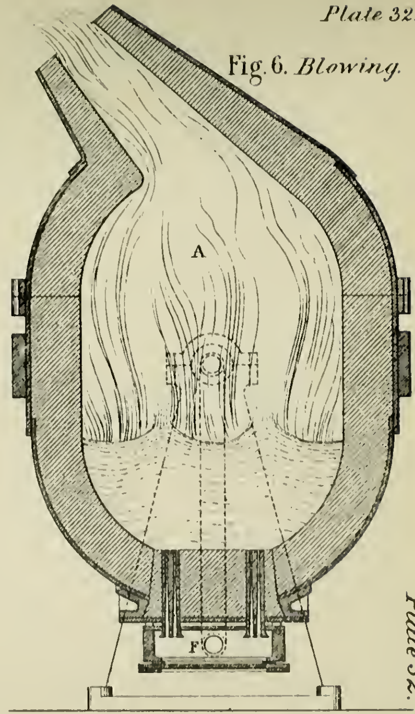


Fig. 6. *Blowing.*



Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

Plate 32.

(Proceedings Inst. M.E. 1861. Page 133)

BESSEMER STEEL.

Fig. 9 Plan of Tuyeres.

Scale 1/20th.

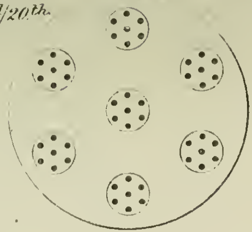


Fig. 10. Longitudinal Section of a Tuyere

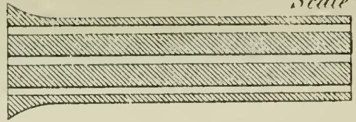
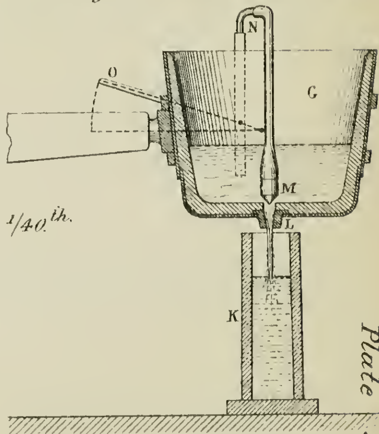


Fig. 11. Plan.

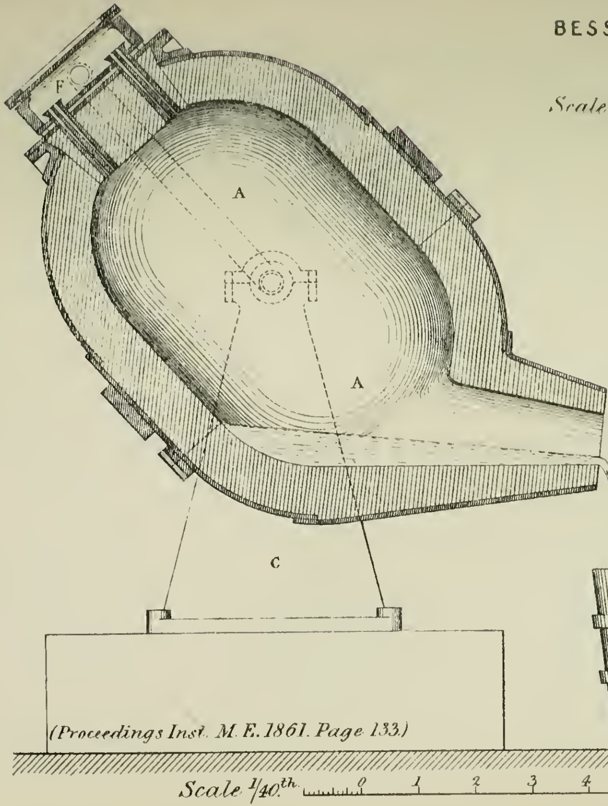
Scale 1/10th.

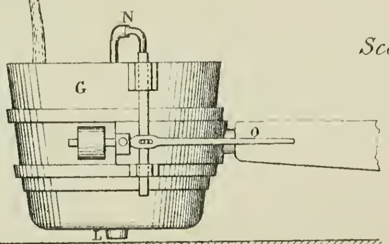
Fig. 8. Vertical Section of Casting Ladle and Ingot Mould.



Scale 1/40th.

Fig. 7. Pouring out the Steel into Casting Ladle.

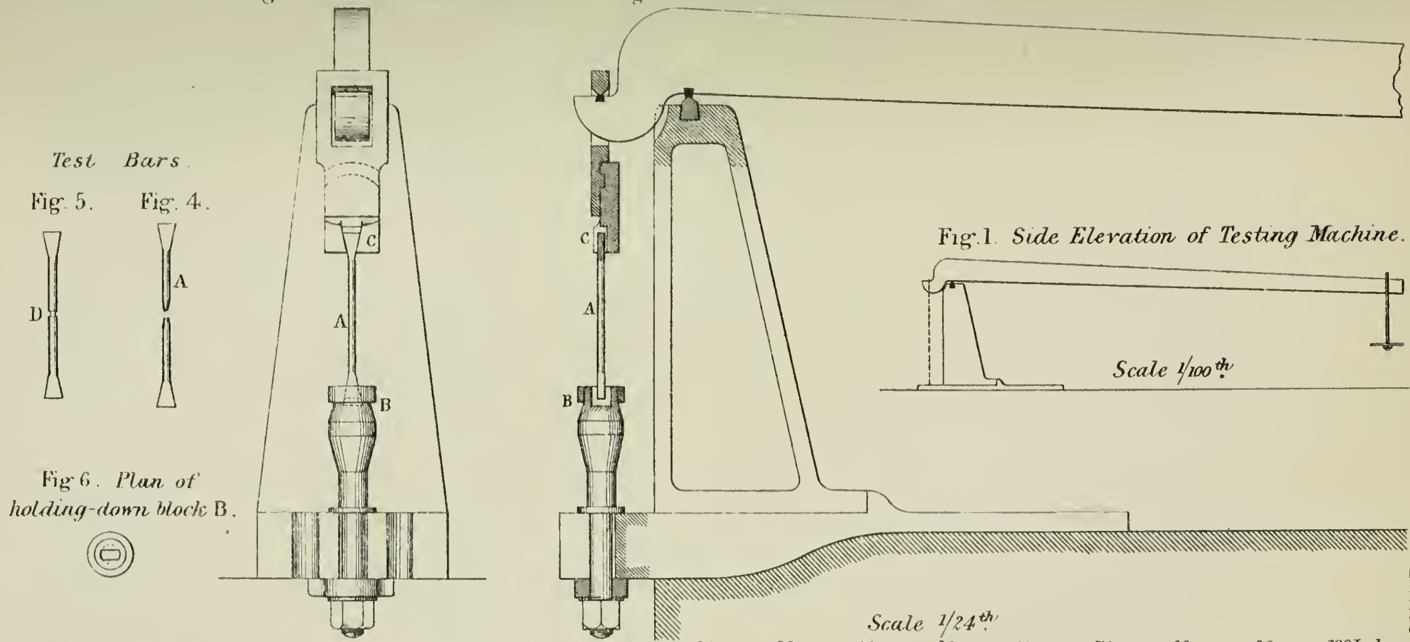




(Proceedings Inst. M. E. 1861. Page 133.)

STRENGTH OF STEEL.

Machine for testing Tensile strength.



(Proceedings Inst M.E. 1861. Page 158)

Plate 34.

STRENGTH OF STEEL.

Mode of testing Transverse strength of Cast Steel Axles.

Fig. 7.

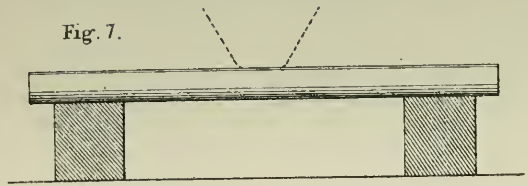


Fig. 8.

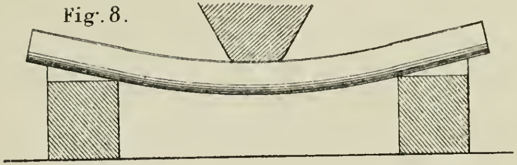


Fig. 9.

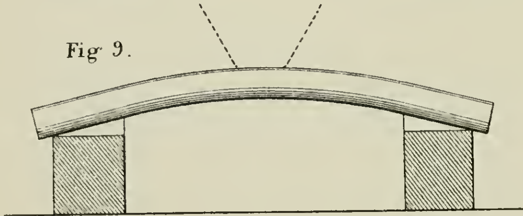
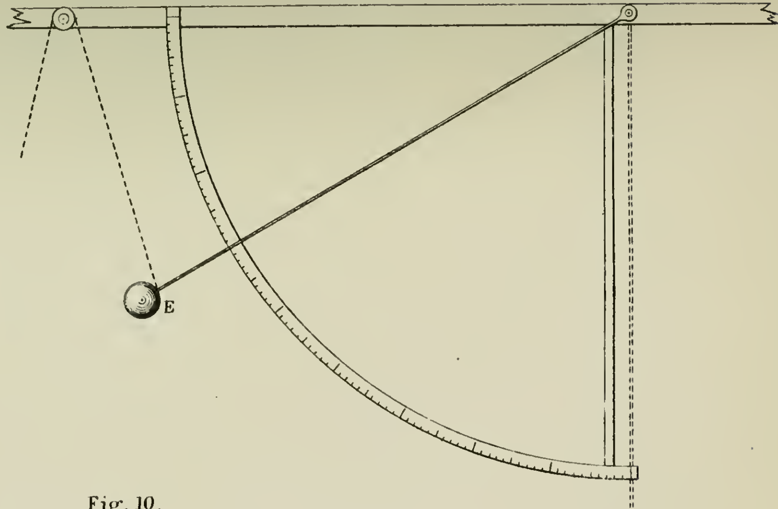
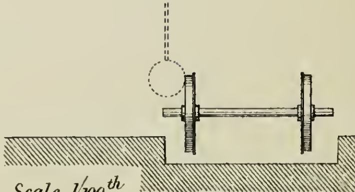


Fig. 10.

Scale 1/24th.

Fig. 11. *Mode of testing Cast Steel Disc Wheel.*





Scale 1/100th.

Plate 35.

(*Proceedings Inst. M.E. 1861. Page 158*)

ON THE CONSTRUCTION AND ERECTION OF IRON PIERS AND SUPERSTRUCTURES FOR RAILWAY BRIDGES IN ALLUVIAL DISTRICTS.

By Lt.-Colonel J. P. KENNEDY, of London.

The object of the present paper is to consider the most eligible construction for the Piers and Superstructures of Railway Bridges in alluvial districts, as regards economy in first cost, and facility and economy of erection in the colonies, in situations where the supply of skilled labour and mechanical appliances are very limited: and more especially in reference to the extension of railways as a means of facilitating the industrial development of the British colonies.

The mutual dependence of the several portions of the British empire renders it a matter of great importance to all branches of trade and manufactures that the greatest possible facilities should be furnished for transport and intercourse in the colonies; and that communications should be opened in the most rapid and economical manner, for enabling colonial produce to reach the seats of manufacture. The importance of this is especially seen when it is considered what a great and rapidly increasing portion of the total exported manufactures of this country finds its market in the colonies and particularly in India, and how rapidly this increase has progressed since improved means of communication have been adopted for conveying the manufactures into the interior of the country, and giving an outlet for the native produce and raw materials. Some remarkable facts are shown by a comparison of the consumption of British manufactures by the colonies and by the rest of the world; the total population of the British empire being now more than 206 millions, or as much as 1-5th of the whole population of the globe, of whom 6-7ths are colonists. The consumption of British exports by the colonies is more than half as much as that by all other countries, and even in the present deficiency of the required facilities of communication, their

consumption has trebled in the last twelve years, while that of the other countries has only doubled in the same time: although in India, from the great deficiency in means of communication, the average annual consumption by the whole population was only 1*s.* 2*d.* per head in 1855, increasing to 2*s.* 3*d.* per head or nearly double in 1859; whilst in Australia it amounted to more than £8 per head, and to between £1 and £4 per head in the other British colonies. The great step in improving the means of internal communication has been the introduction of railways, which have commenced an entirely new era in the development of the resources of these countries; and since the first starting of railways in India in 1849 a remarkable advance has taken place. The annual consumption of British produce has increased from 4½ millions sterling in the previous year to 10 millions in 1855, and to 19¾ millions in 1859; the value to this country having thus been quadrupled within eleven years, and even doubled within the four years ending in 1859, including the period of the mutiny with all its deranging effects on commerce.

In the employment of railways for this object a consideration of great moment is the mode of construction of the piers and superstructures of the bridges, which form so large a portion of the works of a railway in many parts of India and other colonies; the construction of the piers especially having a particular bearing in alluvial districts upon the practicability and cost and the consequent success of the line. A good illustration of this important subject is afforded by the works completed and in progress in the construction of the Bombay and Baroda Railway in India, with which the writer is connected; where a special construction has been adopted for the bridge piers and superstructures, in order to meet the difficulties of the alluvial district through which the railway passes, and attain facility and rapidity of erection combined with economy in total cost.

Most of the Indian railways take their course through rich alluvial plains and valleys where there is only one important natural impediment to their construction, consisting in the bridging of the rivers, many of which must be crossed within tidal influence; and all of them are swept by fierce monsoon currents, while their beds in

general offer the worst class of foundations for the construction of masonry piers. They thus combine the greatest impediments to the erection of the usual description of masonry bridges. The great cost of erecting a bridge across the Thames at London is generally known; and yet in that case there are the best engineering talent and the greatest mechanical aid immediately within reach; and although the natural impediments are of the same class, they are far inferior in degree to those met with in Indian rivers.

The line of country traversed by the Baroda Railway in its level course of 310 miles from Bombay to Ahmedabad is more intersected by rivers of the above character than any other railway in India. So vast did the difficulties appear that the very practicability of constructing the line was seriously disputed; and not without reason, if it were assumed that the bridge piers must be executed upon the old stereotyped masonry plan, and that the engineer would not adopt those modern and well tested improvements that were applicable to the case. To those however who knew the precise nature of the local difficulties as well as the modern engineering improvements by which they could be surmounted, it was clear that this line could be effectually and economically executed, provided such modern improvements were applied: but by no other means could a maximum financial return for the outlay, which ought to be the first principle in engineering, be secured. The object was therefore to show that it was practicable to overcome with rapidity and economy the great characteristic difficulty opposing the construction of Indian railways, even where most prominently encountered. The writer accordingly proceeded to ascertain first all the engineering and financial requirements, and to investigate the comparative merits of all well tested improvements calculated to meet them; whence it was ultimately concluded that to bridge Indian rivers in alluvial districts on the old principle of masonry or brickwork would be both tedious and ruinous to the undertaking; but that the most difficult rivers so situated may be economically bridged by adopting wrought or cast iron for the piers, and wrought iron in the superstructures. The writer finally arrived at one pattern of bridge, admitting of extension or contraction to meet all the variations of circumstances that occur

in such cases, as to height or length of bridge and depth and nature of foundations.

The several applications of the plan to the different situations that are met with are shown in Plates 36 to 39. Fig. 1, Plate 36, is a general elevation, and Fig. 2 a transverse section, of the Taptee bridge, 1891 feet long, spanning a rapid tidal river; and Fig. 3 gives the section of the bed of the river with the variations in depth enlarged eight times, showing the applicability of the same construction of piers throughout the entire length of the bridge.

Fig. 4, Plate 37, shows the construction of piers adopted in strong tidal rivers, such as the Taptee and Nerbudda rivers, where the depth of floods reaches from 40 to 60 feet with a velocity of 6 to 10 miles per hour, and the force of the current acting alternately in opposite directions on the piers requires the addition of oblique piles to act as struts on both sides of the piers. The piers are composed of hollow cylindrical cast iron piles, of 1 inch thickness of metal and 2 feet 6 inches outside diameter, cast in 9 feet lengths weighing about $1\frac{1}{2}$ tons each, as shown enlarged in Figs. 11 to 14, Plate 40; these are of two principal patterns, for the portions of the piles above and below the ground. Those above the ground, Figs. 13 and 14, have flanges outside for bolting them together by twelve 1 inch bolts; while those underground, Figs. 11 and 12, have the flanges inside, bolted together by ten 1 inch bolts, and are flush on the outside so as to offer no resistance in penetrating the ground; they are large enough inside to leave room for a man getting in to bolt the several lengths together properly in the process of erecting. The foundation is obtained by one of Mitchell's screws at the bottom of each pile, of 4 feet 6 inches diameter, which finds its own foundation without the expense of cofferdams or any other artificial preparation of the ground. The upright piles are placed 14 feet apart centre to centre, and are sunk to a depth of about 20 feet in the ground; but where the ground is softer than usual they are carried down deeper, as shown by the dotted lines in Fig. 4, to obtain the requisite strength of foundation. The greatest length of pile used has been 45 feet below the ground and 72 feet above. The oblique piles forming the struts are inclined at an angle of about 30° to the upright piles; they are precisely

the same in construction as the upright piles, and are joined to the latter at about the ordinary flood level by a cap cast at the proper angle, which clips the body of the upright pile. The piles are all connected together above ground by horizontal and diagonal wrought iron bracing, attached to lugs cast on the piles by a pin at one end and a gib and cotter at the other, as shown in Figs. 13 and 14, Plate 40; Figs. 15 to 18 show sections of the horizontal T iron bracings A, and the diagonal angle iron bracings B. The several parts of the bracing act alternately as struts and ties according to the direction of the current, and in consequence of this alternate strain an accurate fit of the bracing is required; to ensure this the joints at one end of each are therefore left to be done in India from measurement on the site, this being the only forging required in India. The outside piles are faced with a double row of timber as a fender to protect them against shocks from anything floating in the water and brought down by the current. The weight of a single complete pier of five piles for two lines of rails, 63 feet high from the foundations, is 75½ tons, and the cost £624 delivered in London.

Fig. 5, Plate 37, is a side elevation of one of the spans of the bridge, shown to a larger scale in Fig. 19, Plate 41, showing the construction of the superstructure, which is that known as Warren's triangular system. Fig. 20 is a plan of one roadway, and Figs. 21 and 22, Plate 42, are an enlarged elevation of the double standard carrying the ends of the girders, and a side elevation of the girder and standard. Figs. 23 to 29, Plate 43, are sections of the bars composing the girders. This form of girder, when manufactured and accurately fitted in England, requires the smallest amount of skilled labour for its erection abroad on reaching its destination; only a few pins and bolts have to be put in for completing the girders, and the skilled labour required for rivetting box girders or lattice girders is avoided. As it is considered that uniformity of parts, as far as practicable, is of as great importance in bridge work as in other mechanical structures, a uniform span of 60 feet is adopted for all the iron bridges on the line, this being considered the most economical in reference to the general heights of the piers. One end of each girder is fixed on the pier, while the other end is left free to move and

carried on a pair of small rollers C, Fig. 22, to allow of expansion and contraction. The weight of the entire 60 feet superstructure for a single line of rails is 24 tons, being 8 cwts. per foot run; and the cost at the present rate of iron is about £400.

Fig. 7, Plate 38, shows the construction of piers adopted for inland rivers with deep water, say 20 to 50 feet deep, but not tidal, where the current is always in one direction only, as shown by the arrow. Here the oblique piles acting as struts are required only on the lower side of the bridge, and the timber fenders only on the upper side. Fig. 8, Plate 39, shows the piers for inland rivers with shallow water of not more than 20 feet depth, where the oblique piles can be dispensed with altogether. Where there is a rock foundation, the screws are omitted, and the piles are simply let into the rock about 2 feet and filled round with cement, as shown in Fig. 9, Plate 39, allowing of great rapidity of erection in this case. The position of the roadway may be either between the main girders, or upon the top of them, as shown in Fig. 10, Plate 39. The upper position is preferable for the roadway, because it combines the effect of both the main girders in resisting forces that tend to produce buckling of the compression beams. The upper or lower position of the roadway however is decided by the amount of headway under the bridge, or the clearance between the bridge superstructure and the highest known flood level of the river, which should not be less than 5 feet. In every case the power of the compression beams to resist buckling is made ample, and a horizontal diagonal bracing of T iron is provided between the cross girders carrying the roadway, as shown in the plan, Fig. 20, Plate 41, continued from pier to pier; and where the roadway is on the top of the main girders, oblique stays are added, as shown in Fig. 10, Plate 39, to secure the requisite stability and freedom from vibration in the roadway and girders.

A valuable proof of the strength of the piers erected in the manner above described, as shown in the drawings, was afforded by the exposure of the Nerbudda viaduct on the Baroda line to the monsoon of 1860 whilst still in an incomplete state, the works having been suddenly stopped by the cholera breaking out among the men. There were at

the time only two piles erected at the last pier which reached into the middle of the stream, without any oblique piles to serve as struts in supporting it, as shown in Fig. 6, Plate 37; but the pier resisted the deepest and fiercest current of the river without sustaining any injury. At this bridge greater rapidity in screwing down the pier piles was latterly attained by applying animal power direct at the extremities of 40 feet levers made fast to the piles, without the intervention of crab winches or other multiplying wheels. Four of these levers, with 8 bullocks yoked to each, were applied to screw every pile. This plan would be applicable to all pier sites not permanently covered with water. Where any considerable depth of water exists, the practice hitherto has been to erect a temporary staging or platform upon timber piles, from which the permanent iron piles are screwed down by a lever and capstan worked by crab winches: but probably a more economical mode would be to use a floating stage carried upon well anchored pontoons. The principal element of strength in these bridge piers is the firm and accurate fixing of the horizontal and diagonal bracings between the piles from the bed of the river upwards. This and other necessary operations in deep water are effected by submarine fitters furnished with Heinke's diving helmets and dresses, which are indispensable in such cases.

Previous to adopting the Warren system for the bridge superstructures, as shown in Figs. 19 and 20, Plate 41, the writer tested a girder of this construction of 60 feet span to the breaking point; and finding the results generally satisfactory, strengthened the parts very considerably in the subsequent designs, rejecting all cast iron, and increasing the quantity of wrought iron beyond previous practice. An additional strength was thereby obtained which has already proved of great service, having enabled the Wiswamuntra bridge to resist successfully the shock to which it was exposed by an accident arising from a malicious plot for destroying a special train on the 17th January 1861; the train was thrown off the line by a rail placed across in front of the abutment, and broke some of the cross girders supporting the rails; but it was brought to a stand without material damage to the main girders and without serious injury to any one in the train. The regular test to which the superstructures

have been submitted in England was 2 tons per foot run, or about double the maximum load that can be placed upon them in practice. This test load was rolled on in trucks from a siding: it caused a deflection of only $\frac{5}{8}$ inch in the centre of each 60 feet span, and upon removing the load the girders recovered their original camber without taking any permanent set. The greatest strain to which any portion of the girders is subjected under the heaviest practical load is $3\frac{3}{4}$ tons per square inch of section.

The piers and superstructures for 95 bridges on this plan of construction have now been sent to India, comprising 477 spans, and making about 6 miles of viaducts upon the Baroda Railway; and the trains on the 132 miles opened within the last year pass over 33 bridges comprising 215 spans of 60 feet each. There has not been a single failure in the foundations with the iron pile piers, though nearly all the foundations were bad; whilst the attempt to erect masonry abutments even for 10 and 20 feet spans has failed in several instances in similar localities.

The rapidity of erection afforded by this mode of construction is well illustrated by the progress made on the second or central division of the Baroda Railway, extending over a length of 80 miles and including the most difficult part of the entire line. Possession of the land for this portion of the line was obtained in October 1858. The average amount of iron bridge viaduct on the northern half of this division, including the Taptee viaduct, was twice the average of the whole: about 40 miles in this locality, or 1-8th of the entire line, included one quarter of the total amount of bridge work. The Taptee bridge, 1891 feet long, spanning a tidal river and erected on an alluvial bed, shown in the diagram, Fig. 1, Plate 36, was opened for the passage of trains in November 1860, within one year from the sinking of the first pile: this great work ranks second in point of difficulty on the entire line. These 40 miles of railway just completed occupied about $2\frac{1}{2}$ years in construction, including 18 iron bridges making up more than a mile and a half of viaduct, which were erected in only 15 months, a remarkable achievement in railway operations. These works being the first of the description executed upon a large scale, the writer was not able to meet with

engineers experienced in their erection. Only one of the engineers on the line had previously erected a Warren girder, and only one had previously sunk a screw pile. None of the others had erected either piers or superstructures of this class; yet in this their first effort in the erection of railway bridges upon iron screw piles their success was as above stated; and with their increased experience they can now erect as many piers at a time as it might be found advisable to carry on simultaneously, each being completed in a fortnight; and they could cover the piers with their superstructures at the rate of one span in every two days. This rate of erection was nearly attained in practice in the construction of the division of the line above referred to.

An important essential to economy and rapidity of construction is to provide beforehand a large proportion of the permanent way and bridge materials, and to have both of them in readiness at the proper commencing point of the line before the earthworks are undertaken. This precaution would add to the economy of the results by enabling the materials to be carried forwards to their intended sites along the railway itself as soon as the rails were laid on formation level; and would admit of rapid ballasting as soon as the earthworks had received their first rains or monsoon seasoning. It would besides have a beneficial effect in consolidating the banks by the transit of heavy loads prior to the ballasting and before opening the line for traffic. In order to secure the greatest regularity in the supply of the materials in India, all the portions of each pier and each span of superstructure should be shipped together in the same vessel.

The system of construction now described aims at maintaining the greatest practicable uniformity of parts and the smallest variety, with the greatest durability of pattern throughout all branches of the railway works. This can only be secured by well considered designs based upon strict tests. The first templates should be the best fitted to their object of any at the time in existence, and should be preserved until some indisputable improvement required a change. The greatest judicious uniformity of parts and designs is essential to the greatest attainable economy, rapidity, and certainty, both in construction and in after working. On this railway precise uniformity has been

established between the corresponding parts of every pier and of every girder in its 95 iron bridges. Without such uniformity it would have been impossible to secure either the greatest precision of manufacture at home, the greatest rapidity of erection abroad, or freedom from the cost, inconvenience, and delay which must attend losses at sea, when each work is upon a special and separate design. In erecting the work each engineer, artificer, and labourer becomes rapidly accustomed to his particular duty and acquires increased expertness in its performance. The work at one point being completed, the men are moved to similar operations elsewhere with similar materials. The object has been to apply to the construction of great public works the principle of manufacturing success, namely repetition of the same operations by the same men throughout.

From the present state of iron structures of this class that have been standing for many years and have been well taken care of, their probable duration for 100 years may be inferred. This would bring them to between the ages of the old Westminster and Blackfriars masonry bridges: the former of these has for the last six years been in process of rebuilding, and the latter is awaiting a similar renovation. A comparison of the rate of cost of the Baroda Railway iron bridges with that of the old Westminster masonry bridge shows that the interest upon the capital saved by adopting the former would in about three years amount to their entire cost, even in the absence of effectual precautions against oxidation. There is however no desideratum in practical engineering of greater importance than the discovery of such a protection against oxidation as shall materially extend the durability of iron structures.

The cost of the entire construction of the Baroda line may amount to about £11,000 per mile; but had the ordinary method of constructing the bridges been adopted, even if at all practicable, the cost must have reached from £16,000 to £18,000 per mile.

In connexion with the railways now in progress in India as main trunks, and considering that the country is at present absolutely without secondary roads converging to them, it becomes important to settle what is the most profitable description of secondary roads to

adopt. That plan will be best which shall enable goods to be conveyed most cheaply, taking into account first cost, maintenance, and working expenses. Comparing an ordinary metalled road with a light tramway capable of being worked either by animal power or by a small locomotive engine, the cost of construction and the maintenance of the tramway may be assumed at double the amount per mile of the ordinary road; but the tractive effect of the same power on the tramway would be eight times that on the road, the effect of gradients being the same on each. Comparing steam with animal power for cost of traction, the former may be taken at half the cost of the latter with four times the speed. It may therefore be considered that the total cost of haulage by steam power on a tramway is one half that of animal power on a tramway, or one sixteenth that of animal power on ordinary roads, the speed being four times as great in both cases.

It is satisfactory that one native Indian prince, the Guicowar of Baroda, has set the example of constructing from state funds a tramroad converging to a trunk railway, having commenced a line of 20 miles length through a rich district from Dubboee to the Meagaum Station on the Baroda line. This is to be opened as a horse tramroad before the next cotton season. Mr. Forde, the late chief engineer of the Baroda line, has undertaken the construction of this tramroad at a cost of £1300 per mile, using rails 12 lbs. per yard and a 2 feet 6 inches gauge. In the writer's opinion both the gauge of a tramroad and the weight of rail ought to be considerably increased beyond those dimensions; the gauge to be say 3 feet 6 inches, and the rail 28 lbs. per yard at least. The introduction of a minor class of railway or tramroad is a question of much importance, requiring the forethought and distinct arrangement of the government. It is quite as essential that a uniform gauge of road, height and gauge of buffers, and clearance gauge, &c., should be established for such minor roads as for the main trunk lines; otherwise there must be endless and costly unloading and reloading as the system becomes developed.

In conclusion it may be observed, with reference to the extension of railway communication in India more especially, that, with due facilities from the government in the construction and working arrangements, the railway companies will find themselves in a most

favourable position to carry out their task, with every element that can secure the most satisfactory results. Taking the Baroda line as a sample, it traverses a vast populous and most productive district; its ruling gradient is 1 in 500; the cost of construction is expected to average about £11,000 per mile, or one-fifth of the rate of much easier lines executed in England; and it is protected by the establishment of a moderate rate of train speed. Such conditions must ensure safe travelling at low fares for the public, together with a liberal remuneration to the shareholders, and thus tend to restore the confidence of capitalists in similar beneficial operations, so essential to the progress both of England and the colonies.

Col. Kennedy observed that the extent of country to be supplied by railways in India was very great, averaging 1000 miles across from west to east and considerably more from north to south. It was intersected by two principal ranges of mountains, the Vindea central range running from west to east, and the Syhadree range 2000 feet high running from the centre of India southwards along the west coast, with a steep declivity towards the sea on the western side but a gradual fall inland on the eastern. In the case of the Bombay and Baroda line great care had been necessary in surveying the country beforehand, to make sure that all branch lines intended to be constructed afterwards would be practicable, and 4000 miles of ground were examined before any steps were taken in commencing the works: this was the more important in so mountainous a country, in order to get the best possible levels along the entire course of the line, and the result was a ruling gradient of 1 in 500. The population of the country and its capabilities of supplying produce were so great as to ensure an enormous traffic for all the railways, and financial difficulties alone kept things back at present; but he was convinced a dividend might be relied upon fully sufficient to secure the requisite capital being raised without the necessity for a government guarantee, which formed as yet the principal obstacle. The vast importance of ready communication through India might be

judged of from the fact that India already consumed a larger amount of British produce than any other country; hence it was that, while her colonies were the main support of the industrial classes at home, England must look to her colonies and to India especially for the maintenance and advancement of that industry; and facility of road traffic was therefore essential for increasing the demand for home productions and for returning larger supplies of raw material.

From the nature of the country it frequently occurred in India that the practicability of building a bridge in a particular locality was the consideration which determined whether there should be a road or not; and the same condition decided the question also as to a railway. The large majority of the lines had to follow the valleys and to cross the rivers frequently, requiring a special construction of bridge piers for the alluvial soil where solid masonry piers were most costly if not impracticable. The piers were thus of vital importance: many kinds of superstructure might be adopted, but on the piers depended the practicability of making the railway. Of the Thames bridges some cost half a million or more, although they were only about 900 feet long; but on the Indian lines miles of bridges had to be dealt with, which must be strong enough to withstand the fierce monsoon floods running at 6 to 10 miles per hour. Hence great strength and durability were necessary in the bridge piers, combined with cheapness of construction; otherwise a railway could not be attempted with any prospect of a successful issue.

Mr. C. Markham asked how the mode of screwing in the piles by animal power was carried out with the piles in the centre of the river.

Col. Kennedy replied that the use of animal power had only latterly been adopted at the great Nerbudda bridge, where a large part of the river bed was uncovered at low water, and it was only in such situations that animal power had been made available direct by means of a long lever. The general practice had been, where the foundations were not always under water, to hoist the piles into the proper position by shear legs and hold them in this position by guides whilst they were screwed into the ground by a crab winch acting on the end of a lever; but where the ground was always

covered with water, a staging was erected on timber piles surrounding the site of the pier.

Mr. C. MARKHAM observed that in the construction of pier now shown the centre pile would have to carry double the weight on the outside piles whenever two trains passed each other on the bridge, but as the centre and outside piles were of the same size, the pressure on the foundations was unequally distributed; and he enquired why a double pile had not been used in the centre, or a single pile of larger size, since the pressure of the load was entirely vertical, and he did not think the bracing adopted would distribute it sufficiently to render the strain equal on all the piles. There had recently been an instance in America of a timber railway bridge constructed of three girders of equal strength breaking down under the passage of two trains, in consequence of the middle girder having to carry half of the entire load.

Col. KENNEDY replied that the strong diagonal bracing of wrought iron shown in the drawings, when accurately fitted, carried the load effectually on to the side piles; so that wherever the weight might be, it was equally distributed over the entire foundation. The centre piles had been proved to have ample strength for the strains to be resisted; for in erecting the Nerbudda bridge the monsoon floods occurred at a time when the piers had advanced into the middle of the river, and only two piles had then been erected in the last pier, without being thoroughly braced; yet the pier withstood the whole force of the current, though it could have had only a small portion of the strength possessed when completed. In the American bridge referred to, the centre girder when bearing the double load of two trains passing at the same time would receive no support from any adjacent parts of the structure: but the piles of the Baroda bridgo piers were mutually supported by the copious and accurately fitted bracing, which necessarily distributed the load equally over the pile foundations.

The CHAIRMAN thought the diagonal bracing shown in the drawings would certainly distribute the weight equally on all the piles, when properly constructed; and it was therefore of great importance that the fitting should be accurately done in erecting the piers.

Mr. C. Markham asked whether there had been any difficulty in fitting together the several lengths of the piles securely, in consequence of the joints of the castings not being faced up.

Col. Kennedy replied there was no difficulty in making a secure joint; the joints of the castings though not planed were chipped to a level face, and bolted together with ten 1 inch bolts for inside flanges and twelve 1 inch bolts for outside flanges; and the joints were found quite satisfactory, whilst the expense of planing them was saved.

Mr. H. Bessemer thought the construction of the pier now described was a valuable application of tubular piles where brick foundations were impossible on account of the nature of the ground. The use of screw piles throughout the structure entailed an amount of labour in screwing them down which might perhaps be avoided in some instances by the plan that he had seen adopted in the pier lately constructed at Southport, where there was difficulty in getting a foundation and cofferdams would have been very expensive, the ground being nothing but sand to a great depth, covered with water at each high tide. The plan adopted was a very simple system, applicable generally for foundations in sand, and consisted in employing tubular piles built up of a number of lengths, having a broad flat disc at the bottom, 4 feet diameter, with a small hole in the centre, through which a stream of water was allowed to flow from a pipe supplied by the water main of the town: the water displaced the sand from under the disc, and in 30 or 40 minutes the pile was sunk 10 or 12 feet deep in this manner; the water was then shut off and left the pile resting on a broad level surface, which afforded resistance enough to prevent the pile sinking further under a heavy load. The only labour required would be for pumping the water, where there was not a supply at hand.

Col. Kennedy said that was Mr. Brunlees' plan, and it had been very successfully applied for the railway viaduct across the sands of Morecambe Bay. It was an excellent mode of sinking piles in sand and no doubt quicker and easier than by screwing them down; but was applicable only where the foundation consisted of sand alone. In the Indian rivers however the soil was alluvial, containing boulders

intermixed with it, which could not be washed away by a stream of water, and the piles had therefore to be screwed in. In one place at the Nerbudda bridge a quicksand obliged the piles to be carried to a depth of 45 feet; but as they passed through other soil also, screw piles were necessary even in this instance.

Mr. E. T. Bellhouse enquired who were the makers of the ironwork for the bridges; he thought a great deal of the success of such works depended on the manner in which they were executed in England previous to erection abroad, and a work of such magnitude as the bridges now described reflected great credit on the makers. He asked also whether the erection in India was superintended by English engineers, and whether it was performed by native labourers or workmen sent out from England.

With regard to the centre pile in each pier he thought it was quite right in this case to make it the same size as the others, and the diagonal bracing was quite sufficient to ensure every single pile receiving an equal share of the weight. It would be very inconvenient to have another pattern of pile, and in that class of work for foreign countries it was highly important to secure simplicity and uniformity of construction, to save cost and trouble in erection.

A serious question in reference to all iron structures, particularly those of wrought iron, was the means of preserving them from oxidation; and he was not satisfied that the right mode of employing wrought iron in bridges and roofs had yet been arrived at, for giving it the greatest protection from rusting. He had had to make several iron structures of similar character, and thought there was too strong a tendency generally to aim at cheapness in first cost, by running the work too fine in size and weight of the parts; and a warning was needed he thought to recall the consideration of durability as of equal importance with that of first cost. Already many proofs had been received of the danger of carrying lightness of construction to an extreme: some fine iron roofs that had been erected within the last twenty years had come down suddenly. He had seen few iron roofs that were properly painted to keep them from rusting; and unless this were frequently done, an accident might occur any day from the metal having become gradually corroded at some unseen part.

Corrugated iron also, whether galvanised or not, soon began to break into holes unless frequently cleaned and painted. This was even a more important consideration in the large wrought iron bridges, of which so many had lately been put up, and he feared some of them would show signs of serious decay before many more years had passed. It was therefore desirable to lay great stress on the necessity of efficiently painting all iron structures, for keeping them in thorough repair and enabling them to last for many years.

Col. Kennedy said that the whole of the ironwork for the bridges had been done by four makers, two of whom supplied the piers and two the superstructure, and the whole of the work had proved thoroughly satisfactory. Of the piers nearly half were supplied by the Horseley Iron Co., Tipton, and the rest by the Victoria Iron Co., Derby. There was always a difficulty in carrying cast iron safely across the sea, from the great risk of breakage in shipment and in conveyance by land as well as the chance of disasters at sea; but they had had altogether only about 5 per cent. of loss from all causes in the cast iron work, which was a smaller proportion than he had ever heard of before in similar cases. The first part of the superstructure was made by Messrs Kennard at Crumlin; but the greater portion by Messrs. Westwood Bailey and Campbell, London Yard, Isle of Dogs. Every wrought iron girder must have some deflection under a load, but the proof of accuracy of workmanship and correct fitting of all the parts was that it should come back to its original position when the load was taken off without any permanent set. For the erection of the work in India the engineers and foremen alone were sent out from England, and all the other workmen employed were natives: the natives made good workmen in a very short time and then got on rapidly with the work. As a consequence of the additional employment, the price of labour had now been doubled by the railway works throughout the district traversed by the line.

He fully concurred in condemning the practice of cutting down the dimensions too fine in such structures, and considered a liberal margin ought to be left beyond the calculated strength, to allow for strains which could not be taken account of with the same accuracy as simple transverse and longitudinal strains. Buckling was a frequent source

of extra strain, particularly where there was any considerable depth of girder, and therefore required to be carefully provided against by increasing the size of the sections and arranging the iron in such a form as would enable it best to resist buckling under compression. In the girders now described all the bars subject to compression were made of a cross shape in section, as shown by the drawings, (Plate 43); and the greatest strain either of tension or compression on any part of the girders amounted to only $3\frac{3}{4}$ tons per square inch under the heaviest practical load.

The CHAIRMAN enquired whether the girders were joined up into one continuous length so as to increase their strength, or whether each span had separate bearings at the ends.

Col. KENNEDY replied that each span had separate bearings, in order to allow perfect freedom for expansion and contraction. Each girder was supported by the top or compression beam, which was fixed to the pier at one end, the other end being left free to move on rollers. The greatest longitudinal motion at present observed in 24 hours amounted to $\frac{3}{16}$ inch in one span of 60 feet. In the dimensions of the girders great allowance had been made to provide against buckling and the strains produced by concussions, and there were only a very few places where the strain ever came up to the maximum of $3\frac{3}{4}$ tons per square inch, while everywhere else it was much below that amount, so that the strains never approached the elastic limit of the iron. The accident to the Wiswamuntra bridge mentioned in the paper was a sufficient evidence of the large margin of strength that existed; for though the beams were bulged out and otherwise damaged in that case by the train running against them when it was thrown off the rails, they still held up the load, and the bridge was not broken down although only a single line of rails had been constructed.

Mr. A. B. COCHRANE asked whether the several lengths of the piles were cast vertically, in order to ensure the same thickness of metal all round, and whether the joints required any fitting to go together properly.

Col. KENNEDY said the pile lengths were cast vertically, and the joints were generally cast with sufficient accuracy to go together without any fitting; but where necessary they were chipped to a

level face, and care was taken to ensure a uniform thickness of metal throughout the flanges.

The Chairman enquired what means had been adopted to protect the ironwork of the bridges from corrosion, and whether galvanising the iron had been tried. The great variety of situations in which iron structures were placed would of course cause the work to be differently affected in different cases.

Col. Kennedy replied that every piece of the ironwork was dipped when hot in a bath of linseed oil, and had afterwards two coats of good oil paint. After erection they relied upon frequent and thorough painting for keeping the iron from rusting. From an examination of several old iron structures he found that the cast iron generally stood well, but the wrought iron showed evidences of corrosion after it had been up about 20 years, and it could never be relied on unless frequently painted or otherwise protected. He had not tried galvanised iron, having seen several roofs constructed of it in which large holes had been made by corrosion.

The prevention of iron from rusting was a question of general importance, and he thought every encouragement should be given to investigation of the subject, with a view to obtaining some really permanent protection. It was quite clear that even with its present liability to oxidation iron made decidedly the cheapest structure for large bridges in general, particularly in alluvial districts: but its durability and renewal were dependent mainly on its thorough protection from oxidation. The object to be sought was not simply to secure the best protection out of a number of modes, of which all might be defective; but to arrive at an absolute means of preservation if that were possible.

Mr. J. F. Spencer observed that tar had proved a very effective material for preserving the bottoms of iron ships from rusting, and was applied also inside the vessels. On the Clyde large ships of 2000 or 3000 tons burden were protected inside with a coat of a varnish made from purified coal tar, which was found a very efficient protection. A clean surface of the iron for laying on the varnish was all that was required, and it had a fine polish; the coat lasted 7 or 8 years when protected by a lining of woodwork in front. The varnish could

be laid on cold, and the smell was all gone in a few days; it cost only about 2*s.* per gallon, which was much cheaper than red paint. This plan had also been applied to the inside of steam boilers, where the uptake from the furnace passed through the steam room of the boiler, and it entirely prevented oxidation and scaling of the iron from the action of the steam; he thought it likely therefore to be suitable for such structures as the bridges described in the paper.

Mr. H. W. Harman enquired what margin had been allowed in calculating the breaking strain of the girders.

Col. Kennedy considered it was of little importance to calculate the ultimate breaking strain, since that was never likely to be approached in practice; it was more important to keep in view the elastic limit of strength, which he thought might be calculated at about 11 or 12 tons per square inch for wrought iron. If the girders were overweighted a permanent set must be produced; but when the size of the ironwork was calculated so as to keep the maximum strain under one-third of the elastic strength, as in the present instance, then no permanent set would occur, if the fittings were all accurately done.

Mr. H. W. Harman thought it was possible to have a certain amount of permanent set without at all detracting from the strength of the girder. As regarded the construction of bridge that had been described, it seemed well adapted for the particular circumstances that had to be met, being specially designed for the alluvial soil of India, and for facility of transport from this country and of erection abroad: but he supposed it was not considered otherwise superior to those more generally adopted in England, where the circumstances were in so many respects different. He was not aware of any bridges of that construction which had been up for many years at present; and being engaged himself in extensive wrought iron girder works he thought the more solid any bridgework was made the better and more durable it would prove, and on that account preferred boiler plate girders wherever practicable instead of lattice girders. In the present instance he observed that many of the pins in the diagonal bracing of the piers were below water and had to be put in by divers; these could not be examined either then or afterwards, but the

divers must be trusted to for putting them in securely, and if any of the pins were omitted the whole pier would be weakened, since the weakest part limited the strength of the whole. He thought the paper afforded very valuable and interesting information in the experience of erecting that kind of bridge on so extended a scale.

Col. KENNEDY said that kind of construction for bridges was only of recent date, but he knew of some bridges of the class which had already been up 7 or 8 years. Some of the pins of the diagonal bracing must of course be put in under water: but the joints of the several lengths of the piles were bolted together above water before the piles were screwed down. The piles were filled with concrete, which made them solid inside, so that each pile stood on a solid foundation of $4\frac{1}{2}$ feet diameter.

Mr. H. W. HARMAN asked whether there was not some difficulty in getting the piles screwed down into the ground true in level, from inequalities in the nature of the ground; and whether any of the piles had been broken in screwing down.

Col. KENNEDY replied that there was some difficulty in getting the piles correct in level, but it was managed by screwing them down a little further if necessary; and as there were four lugs at each end of the several lengths for attaching the diagonal bracing, the level could be adjusted to one quarter of a revolution of the screw. Where the piles stood on a rock foundation a piece of the required length was cut off the bottom of the lowest length, leaving the flange at top for bolting to the next length; or else the rock was cut away deeper to get the proper level. A few cases had occurred of a pile being broken in screwing down, and it was then very difficult to get the screw out again; this was one of the chief difficulties that had been met with in erecting the bridges. At the Nerbudda bridge the sudden abandonment of the work caused by an outbreak of cholera and followed by monsoon floods left some single piles unsupported, which were broken; and one or two of these could not be got out again, so that it became necessary to alter the spans in two cases, selecting fresh sites for the piers in order to get clear of the broken piles. Rapidity of fixing was of special importance in India, for on account of floods and storms the working year for such operations

could be reckoned at only about 8 months; and the facility of erection with this construction of piers and superstructure was so great that by beginning at both ends at the same time they could now bridge the broadest river in a single season.

The CHAIRMAN observed that there was one objection to the Warren girder in its depending upon each single part for its safety, for if one of the pins were to give way the whole girder would come down. That was not the case in rivetted work, where a single rivet might fail without affecting the strength of the girder.

Col. KENNEDY remarked that the parts on which the safety of the girder depended were simple in construction and not numerous, being merely the cylindrical turned pins fitting into the joint holes.

Mr. H. MAUDSLAY thought a great practical advantage had been gained in the construction of bridge now described by reducing that class of work to a regular system, with the least possible variety of parts and the greatest amount of repetition, which were most important objects to be aimed at in mechanical operations. One valuable result obtained was that the loss of any one piece of the work in erecting did not affect the completion of the whole, as all the parts were made to exactly the same patterns.

He thought they were much indebted to Col. Kennedy for his elaborate and careful paper containing so much valuable and practical information, and moved a vote of thanks to him, which was passed.

The following paper was then read:—

ON CAST-IRON TUBBING USED IN SINKING SHAFTS.

By Mr. JOHN BROWN, of Barnsley.

The object of the present paper is to describe the mode now generally adopted in coal mining districts to stop back the feeders of water met with in sinking to the seams of coal, and thus obviate the necessity for pumping. Without giving an historical account of the various schemes that have from time to time been devised for this purpose, it may be mentioned that the first kinds of tubbing used were formed of timber, in the shape either of planks or of a series of solid kerbs, technically termed "cribs," which were wedged tight with wooden wedges. These modes of keeping back feeders of water have now been almost altogether superseded by the use of cast iron tubbing. The course pursued in fixing the tubbing varies to some extent in different districts, but not materially; and the following description of the method practised under the writer's superintendence at sinkings in the midland counties will give generally an accurate account of the whole.

The tubbing consists of plates of cast iron forming segments of the circumference of the shaft; these are built course upon course to the required height, upon a cast iron foundation called a "wedging crib," as shown in Plates 44 to 46. Fig. 1, Plate 44, is a vertical section of a shaft 10 feet in diameter, showing the bottom iron wedging crib A, with an oak one B below it, eight rings of tubbing CC, each 2 feet in height, and the top iron wedging crib D. Fig. 2, Plate 45, is a plan of the tubbing; and Fig. 3 is a plan of the iron wedging crib A. Fig. 4, Plate 46, is a back elevation of one of the tubbing plates, to a larger scale, showing the arrangement of the ribs by which it is strengthened; and Figs. 5 to 8 are horizontal and vertical sections of the plate. Fig. 9 is a section of the iron wedging crib.

In the case of sinking a shaft which it has been previously determined shall be tubbed, the best mode is to hang the lift of pumps either by means of pulley blocks, or what is better still by powerful screws of a sufficient length to permit an ordinary pump tree to be attached and lowered from time to time as the sinking progresses. Some plan of this kind is requisite, because the space which has to be tubbed must be kept quite clear from pumping stays, as it is necessary to have a free access to the sides of the shaft all round the pumps. After sinking below the feeder of water, the first sound stratum met with should be chosen as a foundation upon which to place the cast iron wedging crib A, Fig. 1, Plate 44, for supporting the tubbing; and to preserve this foundation unshaken and free from cracks it is necessary to avoid the use of gunpowder in sinking down the few yards further which are required to afford room for the workmen whilst wedging the crib, and also as a "sump" or well to keep the suction pipe of the pump covered with water and prevent its being continually "on blast."

A space being cut out all round the shaft, as shown at E, Fig. 1, Plate 44, and a perfectly horizontal bed prepared by dressing with a chisel, the iron wedging crib A is laid upon it; dry sheathing deals of about $\frac{3}{8}$ inch thickness and quite free from knots are placed between each segment of the crib, as shown in the plan, Fig. 3, Plate 45. The space F at the back of the crib is then filled up as closely as possible with blocks of dry deal to the height of the crib, the grain being placed vertically; and dry deal wedges, 8 to 9 inches long, $1\frac{1}{2}$ to 2 inches broad, and $\frac{1}{2}$ inch thick at the top, are then driven in until the spaces are closed. Chisels similar to a shipwright's caulking chisel, but with a projection on each side the head, are now driven downwards by heavy hammers, and then drawn out by a lever with a claw at one end which passes under the chisel head; a wedge is then inserted in the hole and driven down as low as possible. This process is continued until it is impossible to drive in another wedge. The true test of a crib being sufficiently wedged is to find that in no part of the deal blocks F can the iron chisel be driven in, whether placed parallel with or at right angles to the crib; when arrived at this stage, the chisel may be inserted as far as the extent of the tapered edge,

but upon attempting to drive it further down even with a heavy hammer, and with the full force of both hands holding it down from above, the chisel will fly up with considerable violence. To secure the wedging crib in a shaft 10 feet diameter in this manner will require 4 or 5 men for not less than 60 to 70 hours. The spaces between the ends of the segments of the crib must then be filled with wood wedges until no more can be inserted. Great care should be exercised to collect the small streams of water that are usually found running down the sides of a wet sinking shaft, and prevent them from falling upon the space at the back of the wedging crib, as it is indispensable that the whole of the wood blocks and wedges be kept dry.

If a good sound foundation be met with free from cracks and fissures, and the wedging crib be laid and maintained perfectly horizontal and of the proper diameter inside, and wedged to the extent above described, it may safely be concluded that the most important part of the work is accomplished: the insertion of the tubbing of course requires considerable care, but unless the crib be laid true and securely the work must necessarily be imperfect and to some extent unsound. In the case of a very long column of tubbing it is desirable to use two or three wedging cribs placed upon one another, each crib being wedged in the manner described: and frequently an oak crib 6 inches thick and 18 inches broad is placed upon the foundation after it has been dressed off, as shown at B in Fig. 1, upon which the iron crib is then laid and wedged as already described. This wooden crib is wedged, but not so tightly as the iron one; since it is found that excessive wedging will cause a wood crib to rise and become warped. The wooden crib underneath gives facilities for underpinning with masonry, or for joining up a lower series of tubbing plates, as the necessary depth in the wood can be readily cut away.

When the wedging crib is completed, deal sheathing $\frac{3}{8}$ inch thick and $4\frac{1}{2}$ inches broad, cut to the proper radius of the shaft, is placed upon the rebate G at the front of the crib, Fig. 9, Plate 46, and upon this is fixed the first ring of tubbing plates. Each ring of tubbing is so placed that the vertical joints between the segments

are opposite to the middle of the segments in the rings above and below, as shown in Fig. 1; and the lowest ring also breaks joint with the wedging crib. Deal sheathing of a similar kind is placed between the vertical and horizontal joints of each ring, as shown in Figs. 5 to 8, Plate 46, the end of the grain always being presented to the shaft. In the case of all the upper plates pieces of deal 2 feet long and cut in a wedge shape are inserted at the back between the tubbing and the rock, as shown at H in Figs. 1 and 2; one piece is placed with the thick end downwards, at the back of the centre and ends of the segments, and another wedge piece with the point downwards is then driven in so as to tighten the whole and prevent the segments being driven backwards during the process of wedging. But the space E at the back of the two lowest rings being greater than in the upper necessitates rather a different treatment; strong pieces of timber are driven in with one end against the rock and the other against the back of the tubbing. As each ring of tubbing is built up, the vertical joints are slightly wedged with deal wedges 4 inches long; but no wedging is done to the horizontal joints until all the tubbing is fixed. The space E at the back of the two lowest rings should be filled up with some material that the water will force down into the crevices and form a water-tight mixture: oakum, horse dung, riddled soil, &c., are very good for this purpose.

If the feeders of water be found near the surface, it may only be necessary to carry up the tubbing plates to a higher level than that to which the water will rise, and then securely and tightly pin them up to the crib and brickwork above. But where the water is met with at a considerable depth and would rise above the stratum which yields it, an iron wedging crib D, Fig. 1, Plate 44, must be put in at the first sound place above, and fixed in the same manner as the bottom crib A; the tubbing is then built up ring by ring, and joined up to this top crib, which has a rebate upon the underside to receive the deal sheathing. A single row of wedges must be driven into the horizontal joints, commencing at the top and going downwards; this process is then repeated from the bottom upwards, taking the vertical joints at the same time, and is continued until an iron chisel

similar to that before described cannot be driven in between the tubbing plates.

The plug hole I, Fig. 4, Plate 46, in the centre of each plate, is left open until the wedging is completed; oak plugs are then driven tightly in, commencing with the bottom plates and proceeding upwards. This must not be done more rapidly than the rate at which the water will rise at the back of the tubbing, in order to afford every opportunity for the escape of air or gas: a sudden closing up of all the holes has been known to cause a pressure so sudden and violent as to fracture some of the plates, which have had to be replaced. In some districts it is not unusual to connect a small pipe with one of the plug holes, and take it up the pit side until the top of the pipe is above the level to which the water will rise, in order to permit the escape of confined air or gas; but this has never been done at any of the collieries which have come under the writer's supervision.

The deepest tubbing with which the writer has had to deal is at the Baddesley Colliery near Atherstone, where a spring of water was found at 220 yards from the surface. The pressure of water at this depth was of course very considerable, and rendered great care requisite in putting in sound castings and fixing them accurately and securely: the tubbing plates used were 15 inches in height.

The upper part of these shafts had been tubbed continuously from 140 yards in depth up to 50 yards from the surface, making a column of tubbing 90 yards in height. The sinking then proceeded dry for 80 yards deeper, when the spring above mentioned was met with. This occurrence had not been at all anticipated, as it is very unusual in the midland counties to find springs of water much below 150 yards in depth. The feeder being too powerful to be drawn out by barrels entailed considerable inconvenience and expense in the arrangements for pumping.

There were two shafts, each 7 feet in diameter, and 12 yards apart, placed in front of the permanent winding engine, which was a vertical high-pressure non-condensing engine with a cylinder of 30 inches diameter. The pit nearest to the engine was called No. 1,

the other No. 2. The water out of No. 1 pit was delivered into an offtake drift 40 yards from the surface, which had been driven up from a valley for more than 600 yards. This gave a height for the water to be pumped at first of 180 yards, without it being known to what depth the spring might continue. As this was of course too much for one lift of pumps, and as the shaft was too small to admit two lifts of 13 inch pipes and give space at the same time for drawing out the sinking dirt, a rather complicated arrangement of pumping gear was rendered necessary.

A standing set of pumps was fixed in a cistern in No. 1 shaft nearly 20 yards below the wedging crib of the upper tubbing, or about 160 yards from the surface. It was deemed necessary to go this distance below before driving through into No. 2 pit, to prevent all risk of letting down the tubbing. This standing set was 117 yards long with a 12 inch working barrel.

In No. 2 pit was hung a lift of 13 inch pipes with a 12 inch working barrel, and commencing with a length of about 67 yards. These pumps were hung in screws, which were attached to wooden rods 6 inches by 7 inches square, the lower ends of the rods being connected by strong ironwork to the suction nozzle of the pump, which was made of a suitable shape for the purpose.

By a series of quadrants or T bobs, pumping beams, and connecting rods, motion was communicated to the pump rods from a crank on the end of the flywheel shaft, which projected through the engine house at a considerable height above the ground. This would not have been the mode adopted, had the existence of the deep spring been at all expected; but under all the circumstances it answered exceedingly well, and accomplished the desired object by keeping the shaft clear of water until the whole of the water was effectually tubbed back.

The 90 yards of tubbing which had been put in the upper part of the shafts was divided into four lengths, of 35, 29, 18, and 8 yards respectively, commencing from the top. At each of the three upper lengths one wedging crib was put in; and at the bottom two metal cribs each 9 inches deep were placed upon an oak crib 6 inches thick.

In pinning up one series of tubbing plates to a wedging crib above, very great care is requisite in order that the upper tubbing may not be disturbed ; the stone must be taken out in short lengths, and a segment put in before the stone to admit the adjoining segment is cut away.

It will very much facilitate the operation of fixing the tubbing in the pit, if the iron wedging crib be laid upon a level and solid place upon the pit bank, and fitted with the deal sheathing to the proper size of the pit; an iron rod turning upon a pivot fixed in the centre of the circle can be used as a template. Upon the crib the various segments should be fixed, and any untrue castings rejected. When the first ring of segments is fitted, the plates composing it should be marked A 1, A 2, A 3, &c., to the whole number in the ring; the second ring of segments should then be placed upon the first ring, and when fitted marked B 1, B 2, B 3, &c.; and so on for every ring, segment by segment. When three or four rings have been thus fitted, they are taken down, the uppermost laid upon the crib, and a similar number of rings fitted above it, each segment being lettered and numbered; and so on with the whole of the tubbing.

The soundness of each casting should be carefully tested with a heavy hand-hammer having a diamond point, and all those rejected that show symptoms of honeycomb or other defects. Too great attention cannot be paid to this, the value of a rejected casting being very small as compared with the loss of time and money that may arise from the failure of an unsound segment fixed to resist a great pressure of water.

In the case of a shaft being required as an upcast, and where the effect of the corrosive vapours given off from the coal consumed in the ventilating furnace would be prejudicial, it is better to set the tubbing back sufficiently to admit of a course or more of brickwork being built in front of it to protect the iron. The writer has seen iron not so protected which has assumed the appearance and character of carburet of iron or plumbago for some depth from its surface, and was soft enough to be cut with a penknife without turning the edge.

It has been attempted in some instances to use tubbing formed of cast iron cylinders of the diameter of the shaft and 4 or 5 feet in

height, with flanges inside and boltholes so that they could be screwed together. This has been found to be a very imperfect and unsatisfactory kind of tubbing, and will not bear the slightest comparison with tubbing composed of segments and wedged in the manner previously described. The large cylinders are very unwieldy, and present great difficulties in passing the pumps and pumping gear at the pit top. In addition to this they do not by any means afford such facilities for repair: if a fracture occur to a single segment, it can be replaced without much difficulty, which would not be the case if a cylinder failed; and practice has shown that wedged tubbing can be made much tighter than that which is bolted.

With regard to the requisite strength of cast iron tubbing at various depths from the surface, the following are the results of some calculations made by Mr. Atkinson of Durham, one of the inspectors of coal mines, which arose out of a recent discussion at the North of England Institute of Mining Engineers upon the relative merits of cast iron and cement to withstand a pressure of water. For a shaft 10 feet in diameter he estimates the thickness of metal in the tubbing should be

at a depth of 20 yards,		0·132 inch thickness of metal.
40	...	0·264
60	...	0·396
80	...	0·528
100	...	0·660
120	...	0·798
140	...	0·936
160	...	1·068
180	...	1·206
200	...	1·362

In practice however it is not found desirable to use at any depth tubbing of a less thickness than half an inch, in order to prevent risk of fracture from blows in the shaft arising from banging of the tubs or fall of coals from the pit bank. It is also better to use tubbing thicker than the theoretical strength, to provide for waste by corrosion. It may therefore be considered that in a shaft of 10 feet diameter the thickness of tubbing should vary from $\frac{5}{8}$ inch at 20 yards deep to $1\frac{1}{2}$ or $1\frac{3}{4}$ inch at 200 yards deep: the thickness varying in different shafts directly in proportion to the diameter of

the shaft, a shaft 16 feet in diameter for instance requiring at an equal depth tubbing twice as thick as that in an 8 feet shaft.

In putting in tubbing at great depths, the writer recommends that the height of the segments should be reduced, as by that means the flanges are brought nearer together; 15 inches is a very convenient height for such cases, 24 inches and 30 inches being used at smaller depths.

The value of tubbing in shafts depends to a considerable extent upon the depth of the shafts. If the feeders of water are found only a short distance above the seam of coal, it will be quite useless to tub back the water in the shaft, because as the coal workings proceed the roof will break down and the water will find its way into the workings. In determining whether to use tubbing or pump the water, very much depends upon the character of the strata that intervene between the water and the coal. The writer knows cases in Derbyshire where shafts 120 and 140 yards in depth are tubbed, and most successfully; in both cases the bottom of the tubbing is 70 yards from the surface, leaving only 50 and 70 yards respectively as the distance of the lowest feeders of water above the coal. The thickness of the seam of coal worked is from 5 to 7 feet, and the workings have extended over a very large area without letting water down.

Tubbing has been very little used in Yorkshire; but there can be no doubt it might have been successfully employed in many instances, and that it will become generally adopted in sinking deep shafts. In Northumberland, Durham, and Lancashire, almost every shaft that has been recently sunk to a considerable depth has been lined with cast iron tubbing where passing through feeders of water. A very important operation of this kind has been performed with great success at Shircoak Colliery near Worksop, in a deep pit belonging to the Duke of Newcastle, and a detailed description of the sinking of this colliery would prove interesting to mining and mechanical engineers; since it is particularly to be desired as advantageous to all parties that all matters appertaining to the very important question of coal mining upon a large scale should be made generally known.

Mr. Brown showed a model of the tubbing, explaining the manner in which the several segments were put together so as to break joint in each successive course, with a layer of wood $\frac{3}{8}$ inch thick laid between the courses of tubbing. He stated that metal tubbing was not much employed at present in Yorkshire, but was in general use in Northumberland, Durham, and Lancashire; and good tubbing was now becoming of great importance from the necessity of sinking deeper shafts, on account of the coal seams near the surface getting exhausted.

The Chairman enquired whether the quantity of water in the shaft was found to increase at greater depths.

Mr. Brown replied that was not usually the case, and it was generally sufficient if the tubbing were carried down about 100 or 120 yards only; but occasionally the shaft required tubbing as deep as 200 or 300 yards from the surface.

The Chairman asked whether any coating with paint had proved a sufficient protection for the cast iron tubbing from corrosion.

Mr. Brown replied that sometimes the tubbing was merely painted or coated with oil, but this was not sufficient to protect the metal from corrosion by the smoke in the upcast shaft, and in that case therefore the segments were set back about six inches on each side of the shaft and lined with brickwork.

Mr. C. Cochrane thought that when the tubbing was protected by being lined with brickwork it would be difficult to find out any leak that might occur behind the brickwork, and it might be necessary to pull down a quantity of the lining to get at the leak.

Mr. Brown said there was certainly that objection to lining the tubbing with brickwork, and the question therefore was whether it was a less evil to run the risk of the tubbing being corroded, or to incur the difficulty of finding out a leak if one took place. In general however the tubbing could be put together tight enough to prevent any leaks occurring, if care were taken also to see that all the castings were thoroughly sound before being put in their places.

The Chairman enquired whether a leakage generally increased after it had broken out.

Mr. Brown replied that the leakage did not increase, and would sometimes take up completely after a time, so that it was best to wait

awhile when a leak had broken out, before beginning to search for it. When the leakage did not stop of itself it was not necessary to take out the segment of tubbing, but the hole could be plugged with wood or the segment wedged up tighter with wood wedges driven in at the joints, so as to be completely water-tight.

Mr. C. Tylden-Wright asked what length of tubbing had been put in at the depth of 220 yards at the Baddesley Colliery in Warwickshire mentioned in the paper; and what was the pressure of the water behind the tubbing.

Mr. Brown said it was 7 or 8 years ago that the tubbing was put in, and he believed the length was 10 or 15 yards. That was the greatest depth at which he had seen tubbing put in a shaft hitherto, and the pressure behind the tubbing was the greatest that he had yet encountered, amounting to nearly 300 lbs. per square inch; the diameter of the shaft was 7 feet inside the tubbing. There were no pipes to the surface of the ground for taking off the gas that accumulated behind the tubbing, but the vent holes left in the segments were plugged up one after another as the water rose, the top holes being kept open as long as possible to ensure the whole of the gas being allowed to escape. He enquired whether any trouble had been experienced in the recent sinking at the Shireoak Colliery near Worksop from the sheeting being blown out by the gas; and what length of tubbing had been required in that case.

Mr. C. T. Wright replied that at the time of putting in the tubbing at the Shireoak Colliery the wood packing had been blown out of the joints by the gas and the tubbing itself disturbed, from want of vent pipes to carry off the gas from behind the tubbing; but these had since been added in the lower lengths of the tubbing, and it had now stood for two years without giving any further trouble. There were two pits sunk at that colliery, each 12 feet diameter inside the tubbing, which was lined with 3 inches thickness of brickwork to protect it from corrosion, reducing the working diameter to $11\frac{1}{2}$ feet. The tubbing extended a total length of 170 yards from the surface in each pit, and consisted of eleven lengths, the total weight of cast iron used being more than 1200 tons. The pressure of water behind the tubbing was about 190 lbs. per square inch at the bottom.

Mr. Brown enquired what was the nature of the ground through which the sinking was made.

Mr. C. T. Wright replied that the pits were sunk for the purpose of winning the Top Hard coal, which lay at a depth of about 515 yards at that place. The sinking passed through the magnesian limestone for a distance of 36 yards, and afterwards through a very hard gritstone 66 yards thick, in which were the largest springs of water at about 25 yards below the limestone. It had been hoped at first to keep the shafts clear of water by pumping, and two sets of 14 inch pumps were employed for the purpose; but the great feeders of water here met with, yielding as much as 500 gallons or $2\frac{1}{4}$ tons of water per minute in the two pits, rendered it impossible in regular work to keep the water down by the pumps, and it was therefore necessary to have recourse to tubbing. The rock yielding the water however was so strong that the coal below could have been worked away to within 40 yards of the bottom of the tubbing, without any fear of the rock falling in and letting the tubbing come down.

Mr. J. Fernie asked what was the thickness and size of the segments in the tubbing at Shireoaks, and whether any of them had broken.

Mr. C. T. Wright said that each course of tubbing was 12 inches high, and there were 12 segments round the circle, each weighing $3\frac{1}{4}$ cwts. The thickness of metal was $1\frac{1}{8}$ inch at the bottom of the shaft, and each segment was strengthened by three ribs on the back: a lighter description of tubbing only $\frac{3}{4}$ inch thick, and each course 24 inches high, was used in the upper part of the shaft for passing through the magnesian limestone. Several of the segments had broken from being wedged in too tight, all of which broke through the centre plug hole; these had to be taken out and replaced, and on one occasion 7 yards' length of the tubbing had to be taken out for replacing the broken segments.

Mr. Brown enquired how far the tubbing was made to extend at top and bottom beyond the strata yielding the water.

Mr. C. T. Wright replied that the tubbing extended at the top to the surface level, but at the bottom 1 foot below the point where the water was met with was enough, because the rock at that part

was very hard and impervious to water. The joining of each length of tubbing to the length above was made by casting matching plates of the size required just to fit in the space left, instead of filling it up with an oak crib, as he considered wood was too soft to be employed permanently in tubbing on a large scale.

Mr. H. Maudslay enquired whether compressed oak had been tried for wedging up the segments.

Mr. C. T. Wright had not tried it, but pitch pine was used in preference to oak for the packing and wedging between the segments, as containing more gum and swelling to a greater extent, so as to tighten the segments more effectively.

It was most important for metal tubbing in shafts that some effectual means of preventing corrosion should be adopted, as it would be a very serious and dangerous operation to take out any segment under such a great pressure as there was behind the tubbing at Shireoaks. At present the tubbing had stood perfectly well, being lined with 3 inches thickness of brickwork; but the pressure pipes passing up the shaft from the tubbing to the surface became greatly corroded, and both pipes and taps had occasionally to be replaced. The main pipes were strong cast iron gas pipes of 3 inches bore, with gas pipes of $1\frac{1}{4}$ inch bore to the lower lengths of tubbing, and were well coated with tar; but the corrosion took place mainly on the inside, the water being so corrosive as to eat through the pipes in the downcast shaft; the quantity of water flowing through the pipes in both pits was altogether about 200 gallons or nearly a ton of water per minute.

Mr. H. Maudslay suggested that a good plan for coating iron with tar was to heat the iron to a black red heat and then plunge it while hot in the tar; he had seen some gas and water pipes intended for works in France which had been coated in that way, and the surface of the iron was then clean for receiving the coating of tar.

Mr. C. Cochrane said that they had for many years made a regular practice at their works at Dudley of coating cast iron pipes both outside and inside with a mixture of pitch, napthaline, and oil, kept hot in a tank; the pipes were dipped in it while nearly red hot, after having been previously cleaned and dressed, and were then taken

out and left to dry, the surplus draining off them. This preparation had been used extensively for coating water pipes, and formed a very efficient and durable protection to the metal, resisting corrosion for many years. He had proposed applying it to the tubbing of their pits in the north of England, but had not yet tried it for that purpose.

Mr. A. B. Cochrane said that water pipes coated in that way had now been laid 10 or 12 years in Manchester, and were found to be thoroughly preserved from corrosion. The coating looked like a black varnish, and adhered very closely to the metal; and when the pipes were properly coated before the iron had become at all rusted they continued after many years as good as when laid down. In some pipes that he had made for the Melbourne water works the coating came off at places where the metal had rusted before it was put on, and they had to be cleaned and done over again; but they stood the voyage and laying in the ground without injury to the coating, and there was no fear of its getting scraped off with moderate care in handling the pipes.

Mr. R. Chrimes had seen the water works pipes at Manchester, 24 inches diameter, and the coating upon them appeared as perfect as when they were laid down. Some of the pipes had been left lying in the street for a year or two before being put in the ground, but the coating remained uninjured notwithstanding the rough usage they had been exposed to. The mixture described seemed to answer well for cast iron pipes, but he believed it did not succeed on wrought iron pipes.

Mr. C. Cochrane suggested that the addition of sulphur would probably render the coating suitable for covering wrought iron.

Mr. J. Manning observed that the process now described was that of Dr. Angus Smith of Manchester, and was extensively used for coating cast iron pipes with complete success. The composition made a covering like a smooth black varnish, and was heated to the boiling point in an open boiler 10 or 12 feet deep, into which the pipes were lowered in bundles while still very hot.

Mr. H. Woods remarked that a coating of glass enamel made a very perfect protection from corrosion; he had tried it for wrought

iron pipes from 2 to 5 inches in diameter in a large brewery and it answered admirably; and he had seen pipes up to 3 inches diameter which had stood a very high pressure without the enamel being affected.

Mr. A. B. Cochrane thought the cost of that process was too great to allow of its being much used for ordinary work, and the glass would not bear the rough work it would be exposed to in pits, but would soon get chipped off. The mixture of pitch however seemed applicable with much advantage for cast iron tubbing; the segments of the tubbing might be dipped in it before the iron got cold after casting, and the cost of the process was moderate.

Mr. E. Riley thought the most effectual protection for wrought iron against corrosion was a coating of carbon deposited on its surface, which was accomplished by cleaning the surface of the iron and burning oil, tallow, tar, or some other hydro-carbon upon it. He had found iron thus treated resist the action of acid fumes for a long period.

The Chairman remarked that the subject of the paper was of interest not only to the owners of mines but to all persons residing near, since the effect of the shaft would be to drain all the springs in the neighbourhood if it were attempted to keep down the water by pumping; and it was therefore very desirable that the water should be efficiently stopped back by tubbing, to save the constant waste and expense of pumping.

He proposed a vote of thanks to Mr. Brown for his paper, which was passed.

The CHAIRMAN said he had great pleasure in proposing a special vote of thanks to the Local Committee and the Honorary Local Secretary, Mr. T. F. Cashin, for their kindness in making the excellent arrangements for the meeting, which had been attended with such complete success.

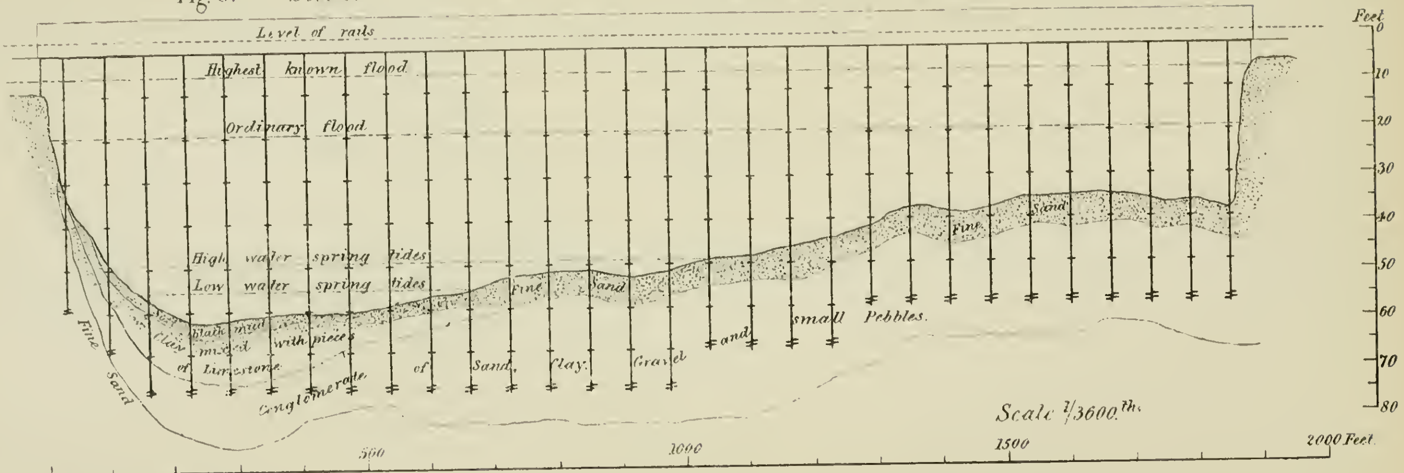
The Meeting then terminated, and in the evening a large party of the Members and their friends dined together at the Cutler's Hall.

On the following day the Members were taken by the Local Committee an excursion to Chatsworth and the neighbourhood, when, by the kindness and special permission of the Duke of Devonshire, Chatsworth house and grounds were thrown open to them, and the large fountains shown in full operation; and the Members were invited by the Local Committee to a handsome entertainment in the park.

Fig. 1. General Elevation of Taptee Bridge. 1891 feet long

Fig. 2. Transverse Section.

Fig. 3. Section of bed of river (vertical scale enlarged eight times.)



(Proceedings Inst. M. E. 1861. Page 171.)

INDIAN RAILWAY BRIDGES. *Plate 37.*

Fig. 4. *Construction of Piers in strong tidal rivers.*

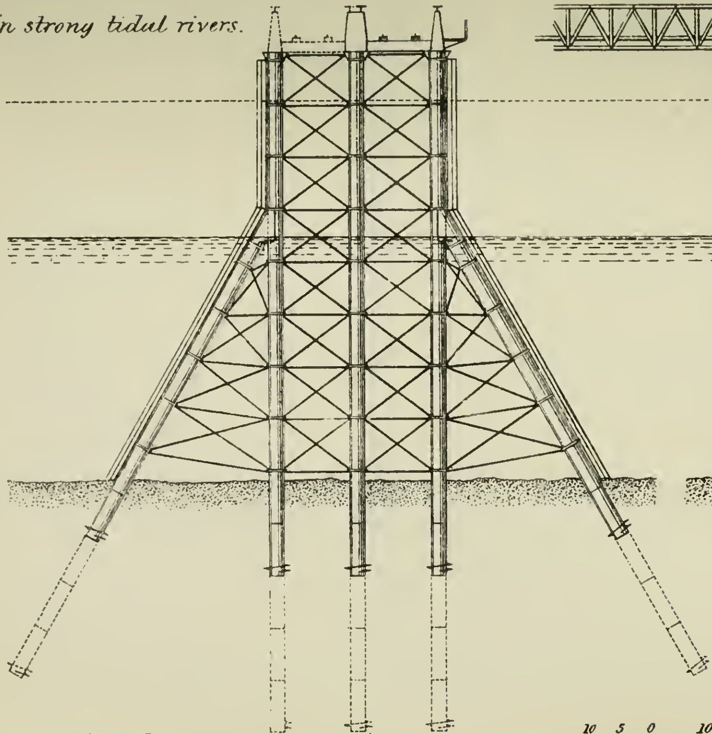


Fig. 5. *Side Elevation of one span of bridge.*

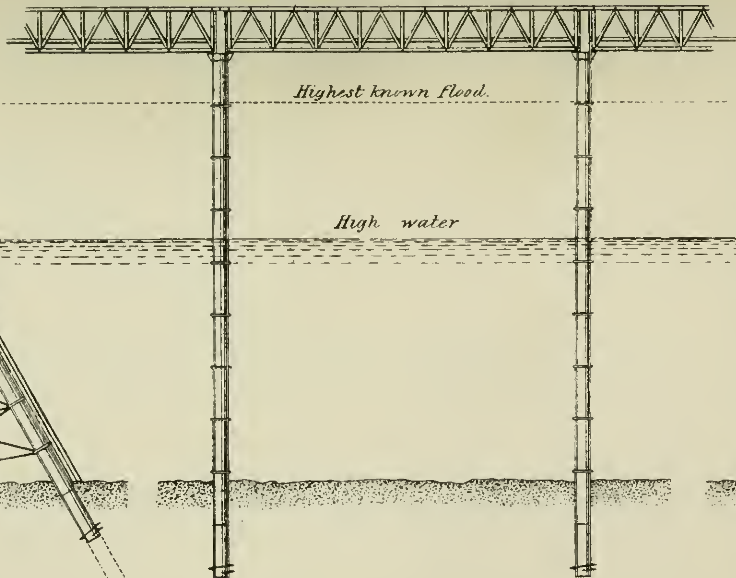
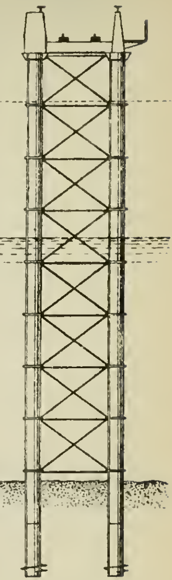


Fig. 6.

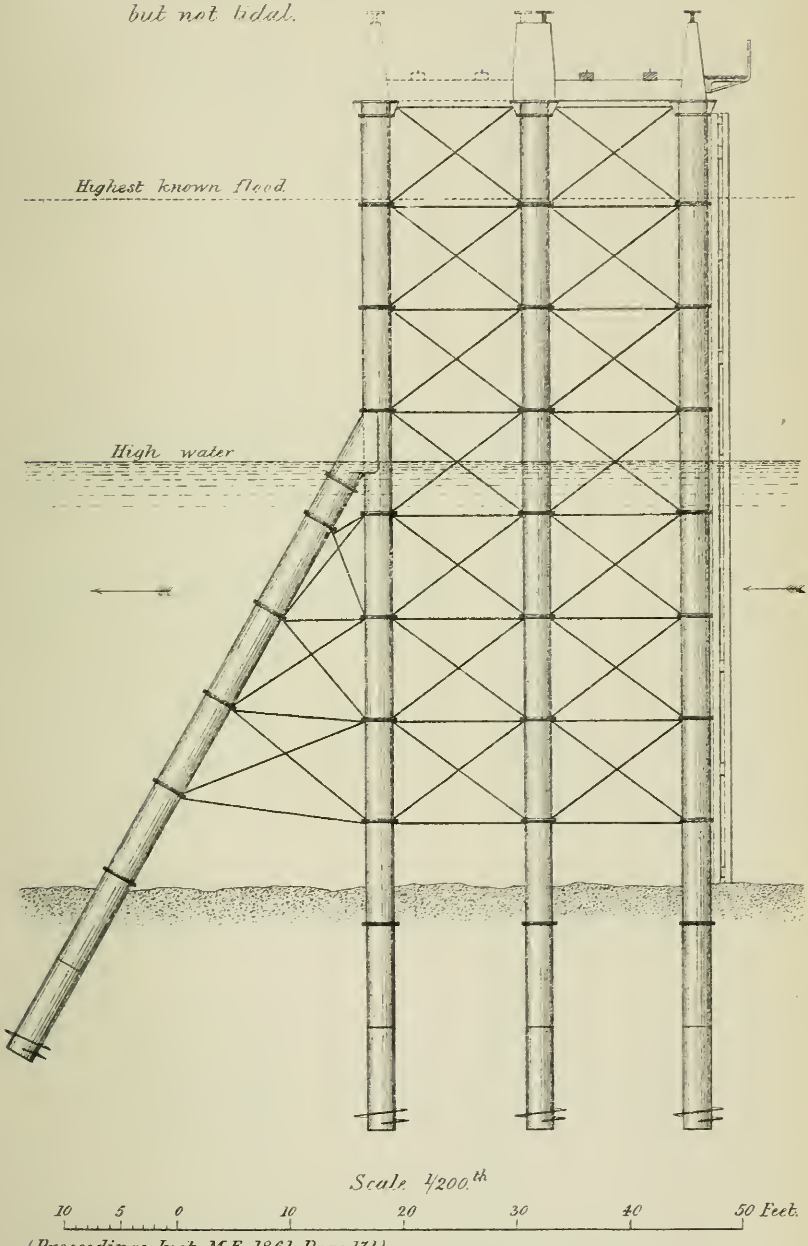


Scale 1/400th.

10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 Feet.

(Proceedings Inst. M.E. 1861. Page 171.)

Fig. 7. *Construction of Piers in inland rivers with deep water, but not tidal.*



(Proceedings Inst. M.E. 1861. Page 171)

INDIAN RAILWAY BRIDGES.

Fig. 8. *Construction of Piers in inland rivers with shallow water.*

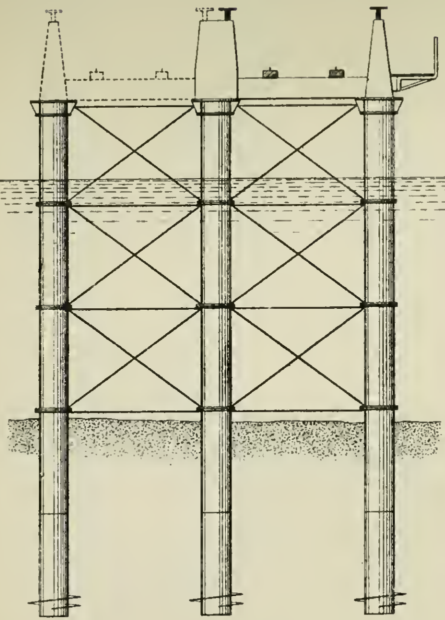


Fig. 9. *Construction of Piers for rock foundations.*

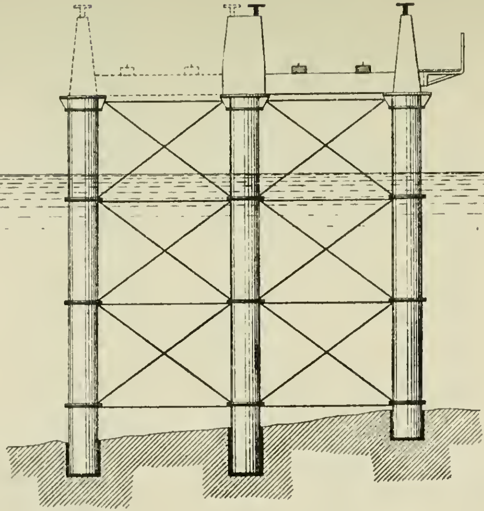
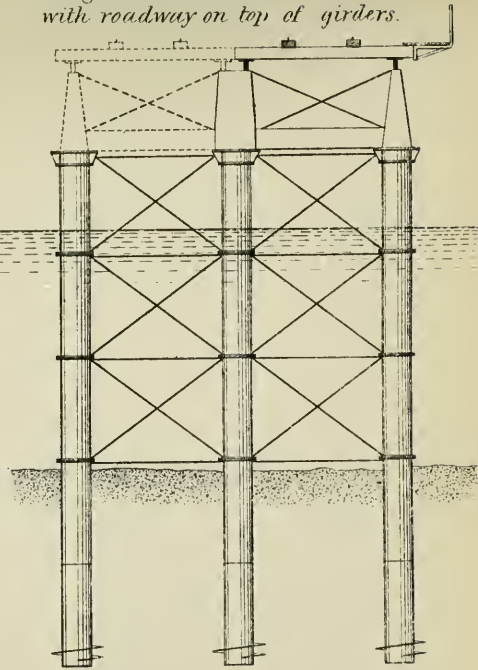


Fig. 10. *Construction of Piers with roadway on top of girders.*

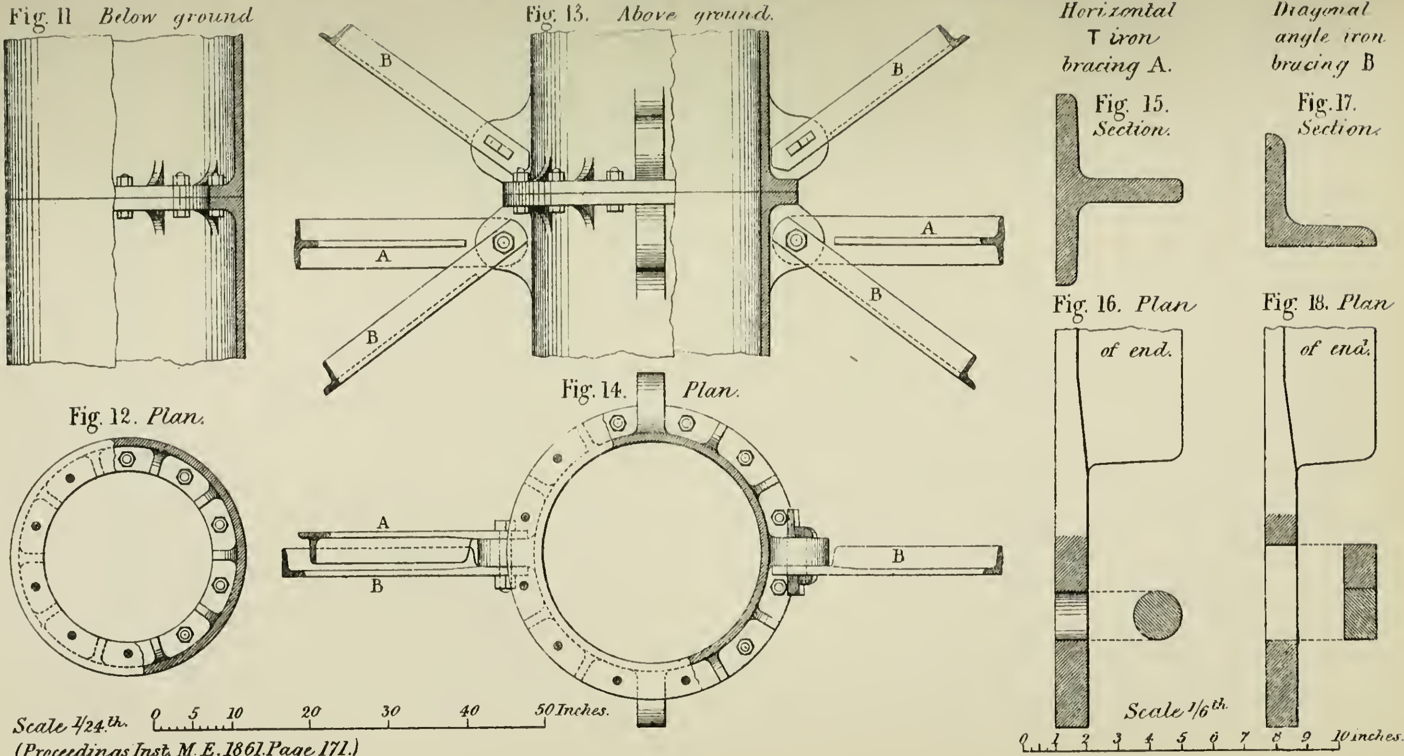


Scale 1/200th. 10 5 0 10 20 30 40 50 Feet.

(Proceedings Inst. M.E. 1861. Page 171.)

INDIAN RAILWAY BRIDGES.

JOINTS OF PILES AND ATTACHMENT OF BRACINGS.



(Proceedings Inst. M. E. 1861. Page 171.)

Fig. 19. *Side Elevation of one span of Superstructure.*

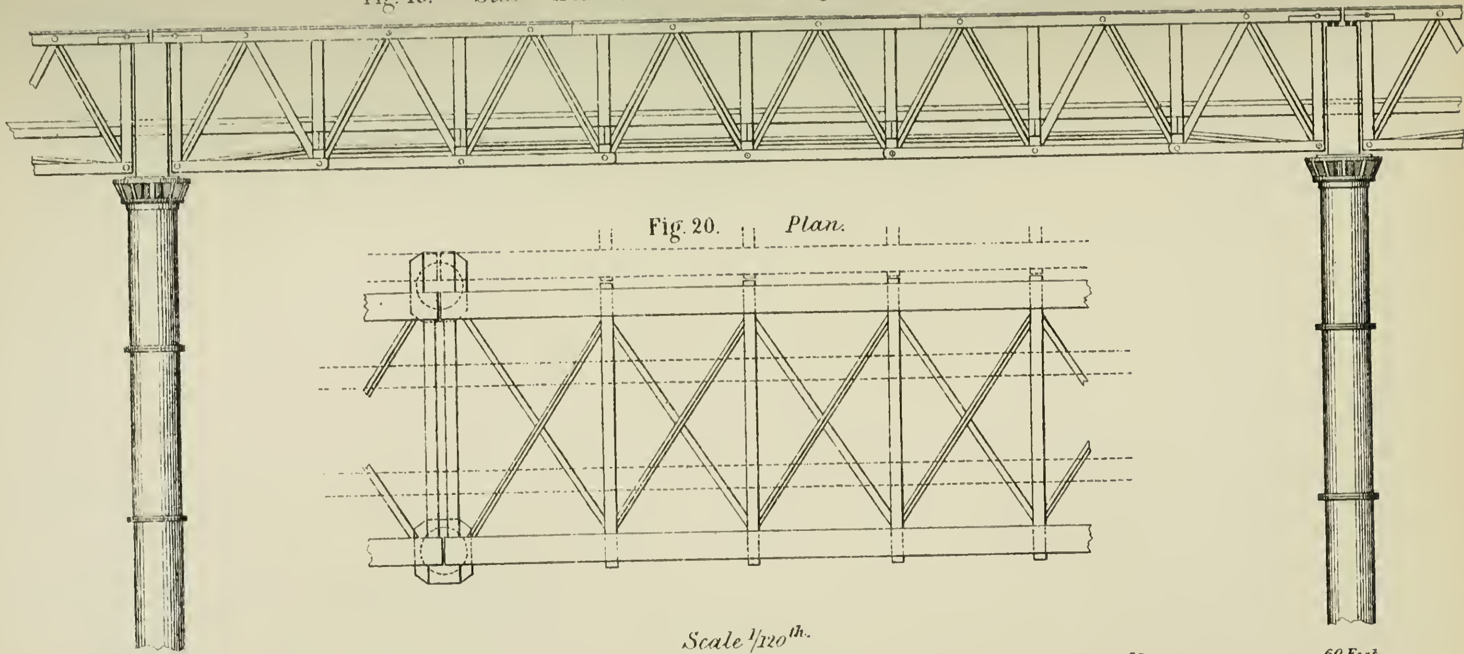


Fig. 20. *Plan.*

Scale 1/120th.

0 5 10 20 30 40 50 60 Feet.

(Proceedings Inst. M.E. 1861. Page 171)

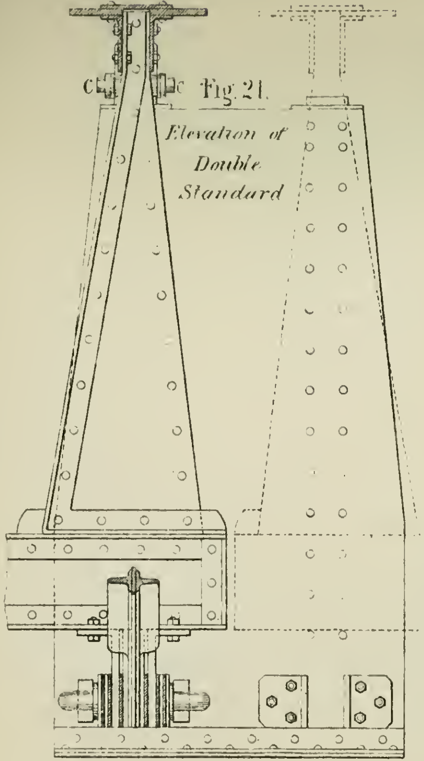


Fig. 21. Elevation of Double Standard

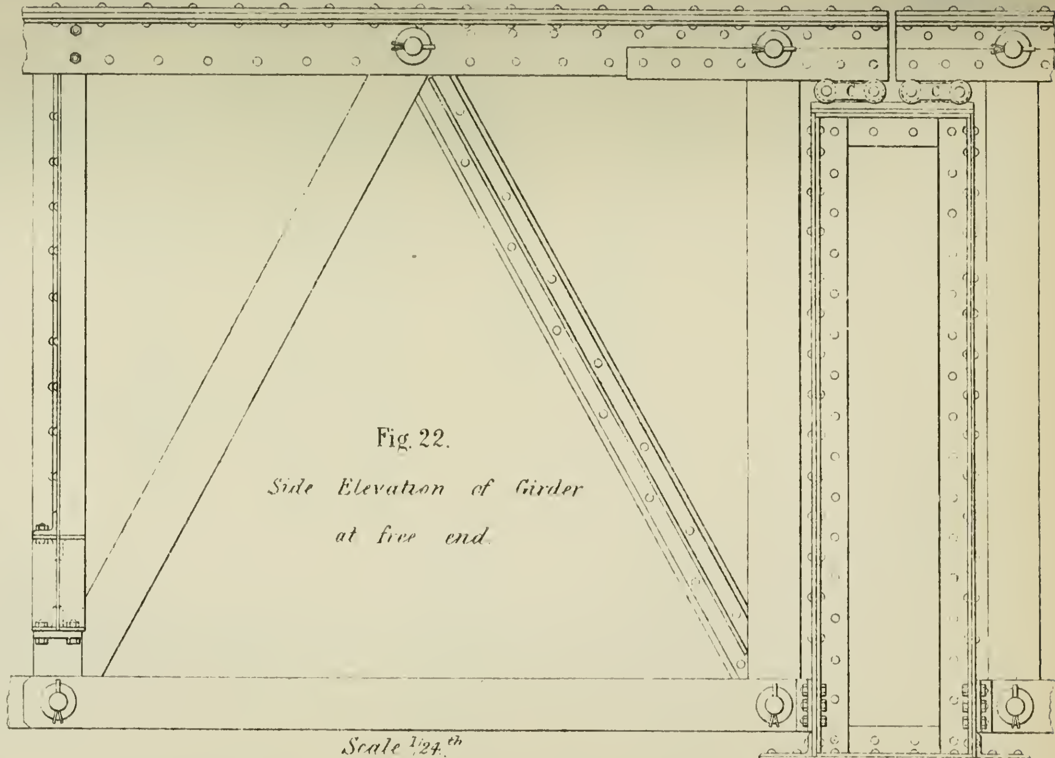


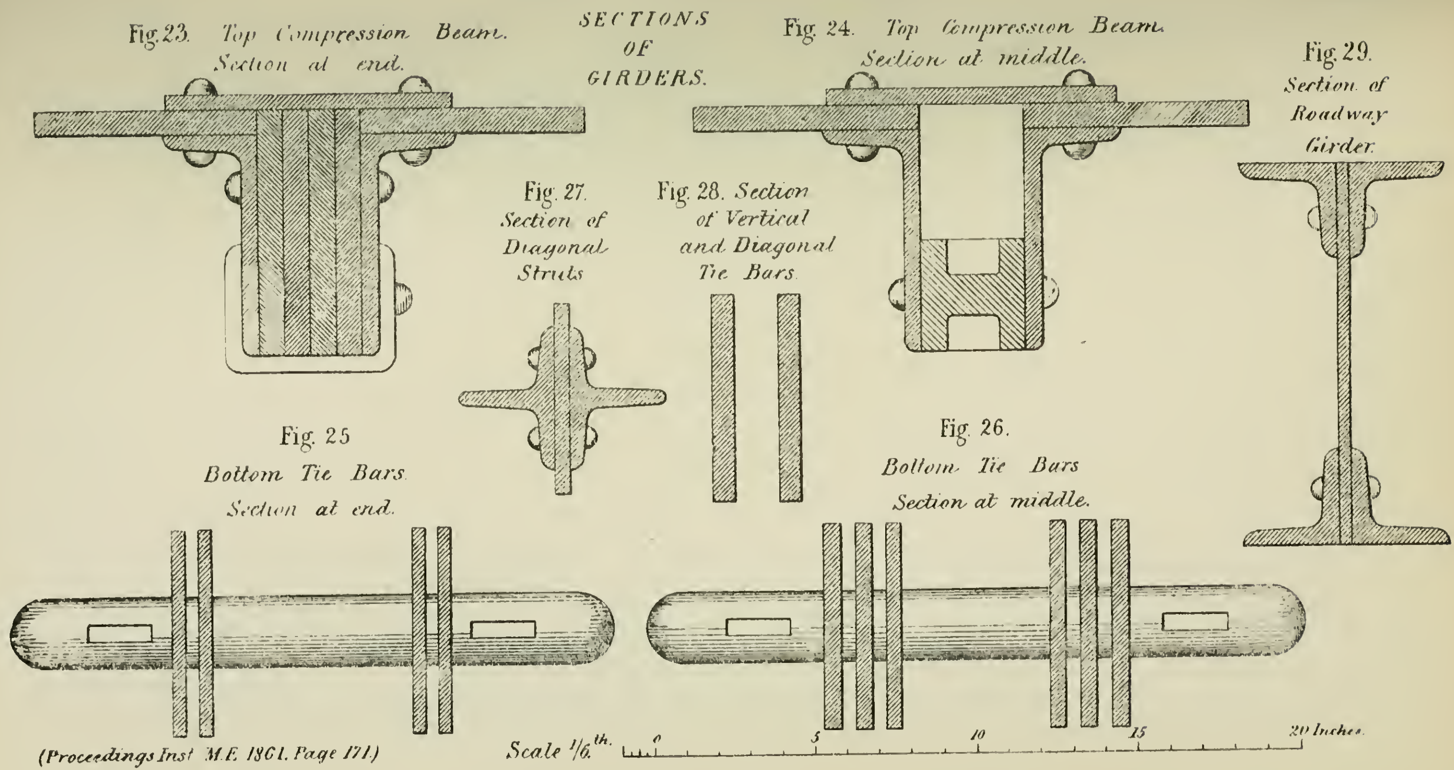
Fig. 22. Side Elevation of Girder at free end.

Scale 1/24th

0 10 20 30 40 50 60 70 80 90 100 Inches

(Proceedings Inst. M.E. 1861 Page 171)

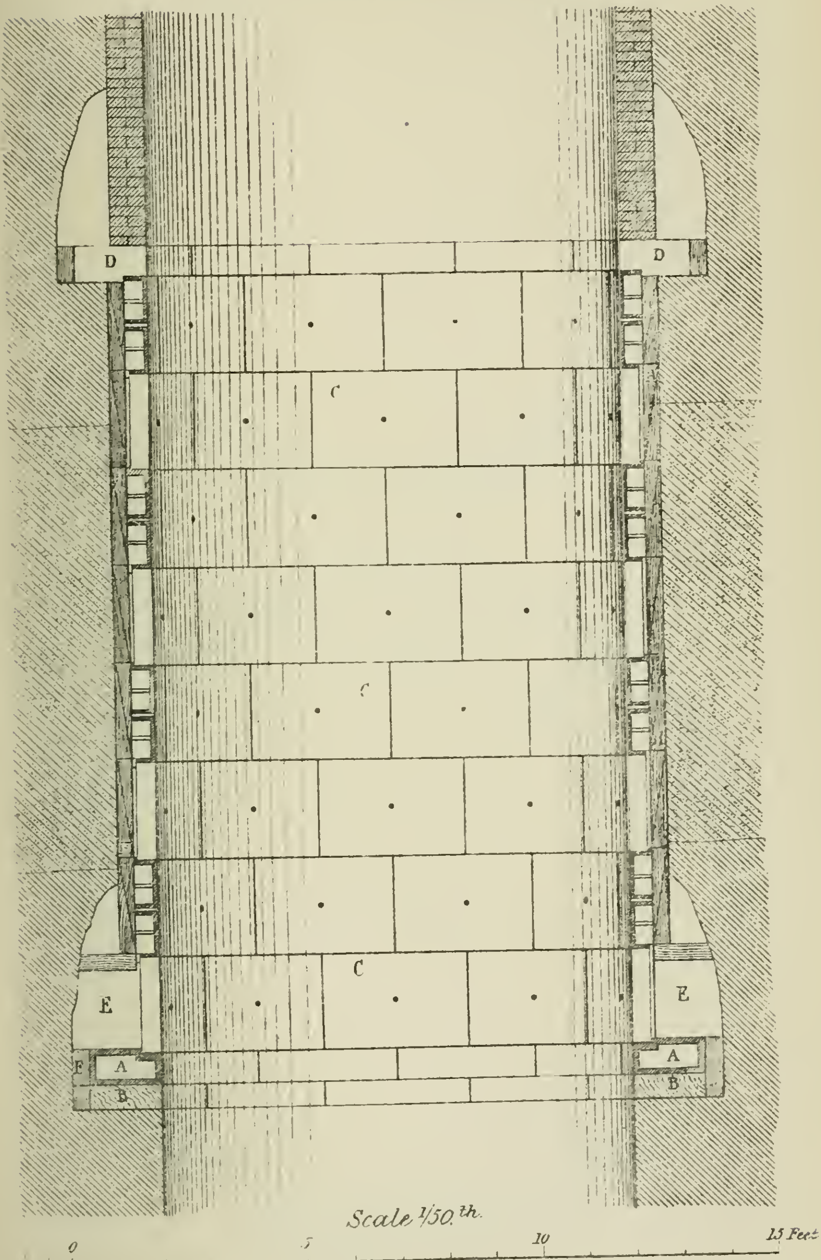
INDIAN RAILWAY BRIDGES.



(Proceedings Inst. M.E. 1861. Page 171.)

CAST IRON TUBBING. *Plate 44.*

Fig. 1. *Vertical Section of Shaft with Tubbing.*



(Proceedings Inst. M.E. 1861 Page 193)

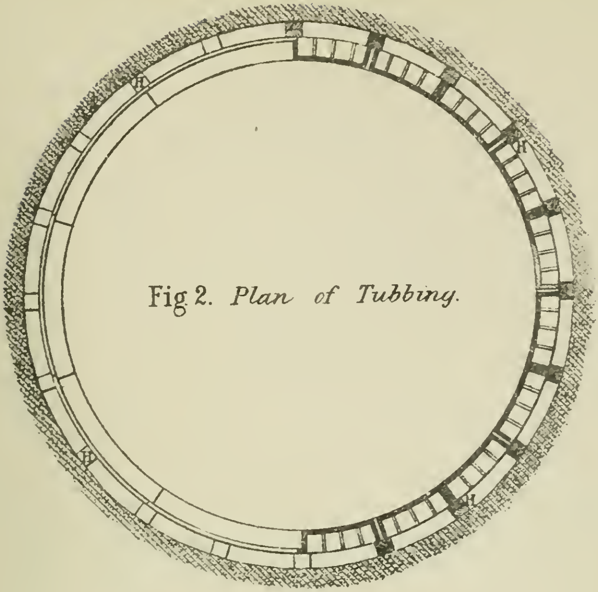


Fig. 2. *Plan of Tubbing.*

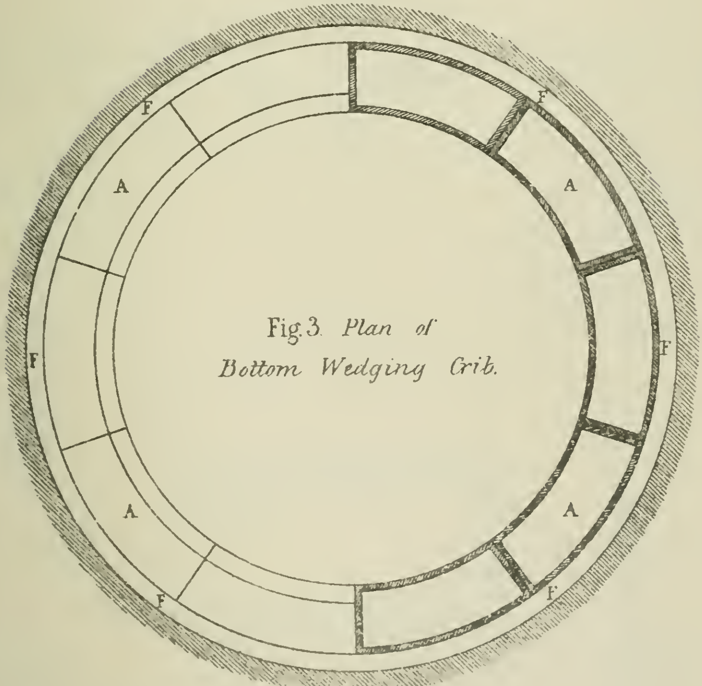


Fig. 3. *Plan of Bottom Wedging Crib.*

Scale 1/50th 0 5 10 *Feet.*

CAST IRON TUBBING. *Plate 46.*

Fig 4 *Back Elevation of Tubbing Plate.*

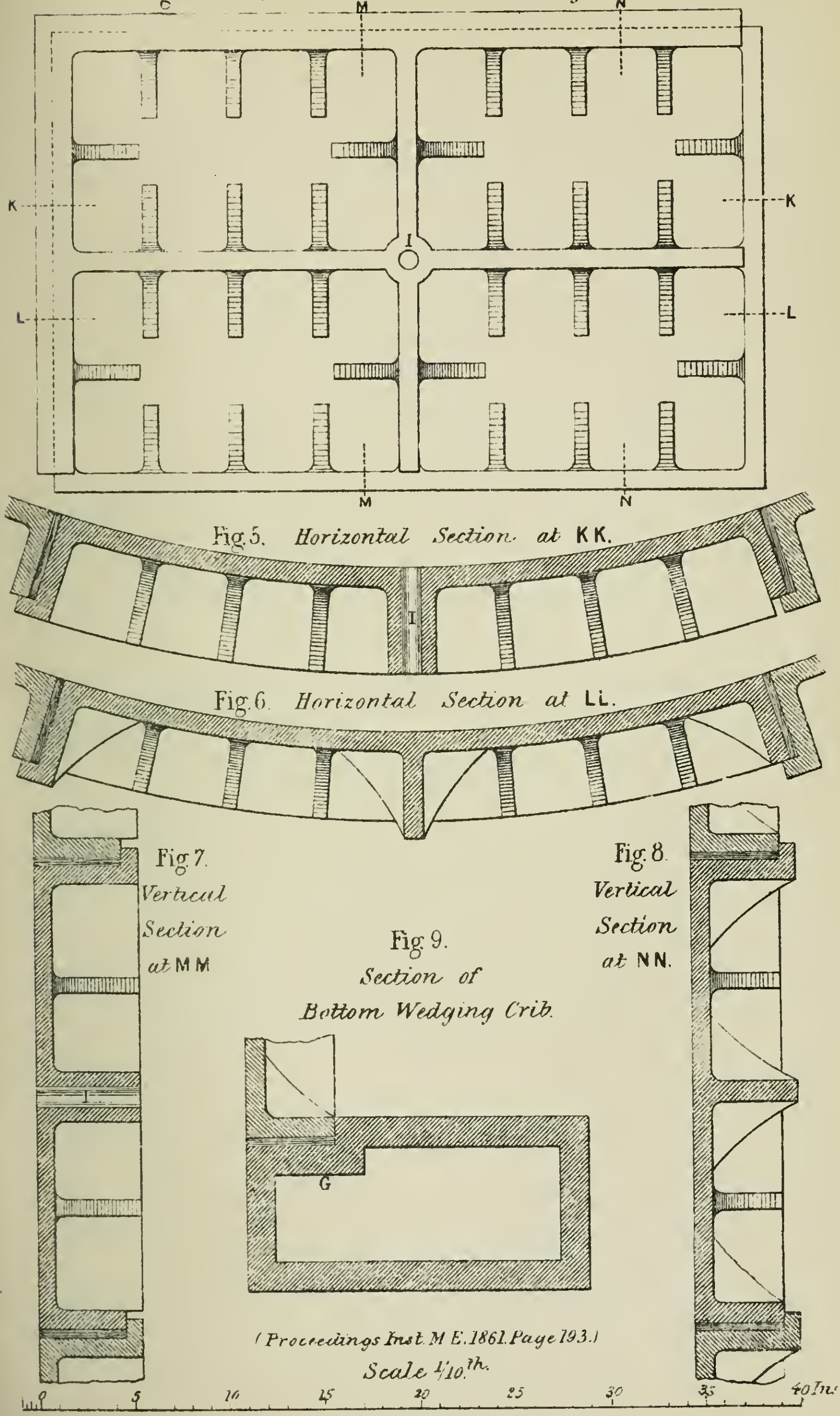


Fig. 5. *Horizontal Section at* KK.

Fig. 6. *Horizontal Section at* LL.

Fig. 7. *Vertical Section at* MM

Fig. 8. *Vertical Section at* NN.

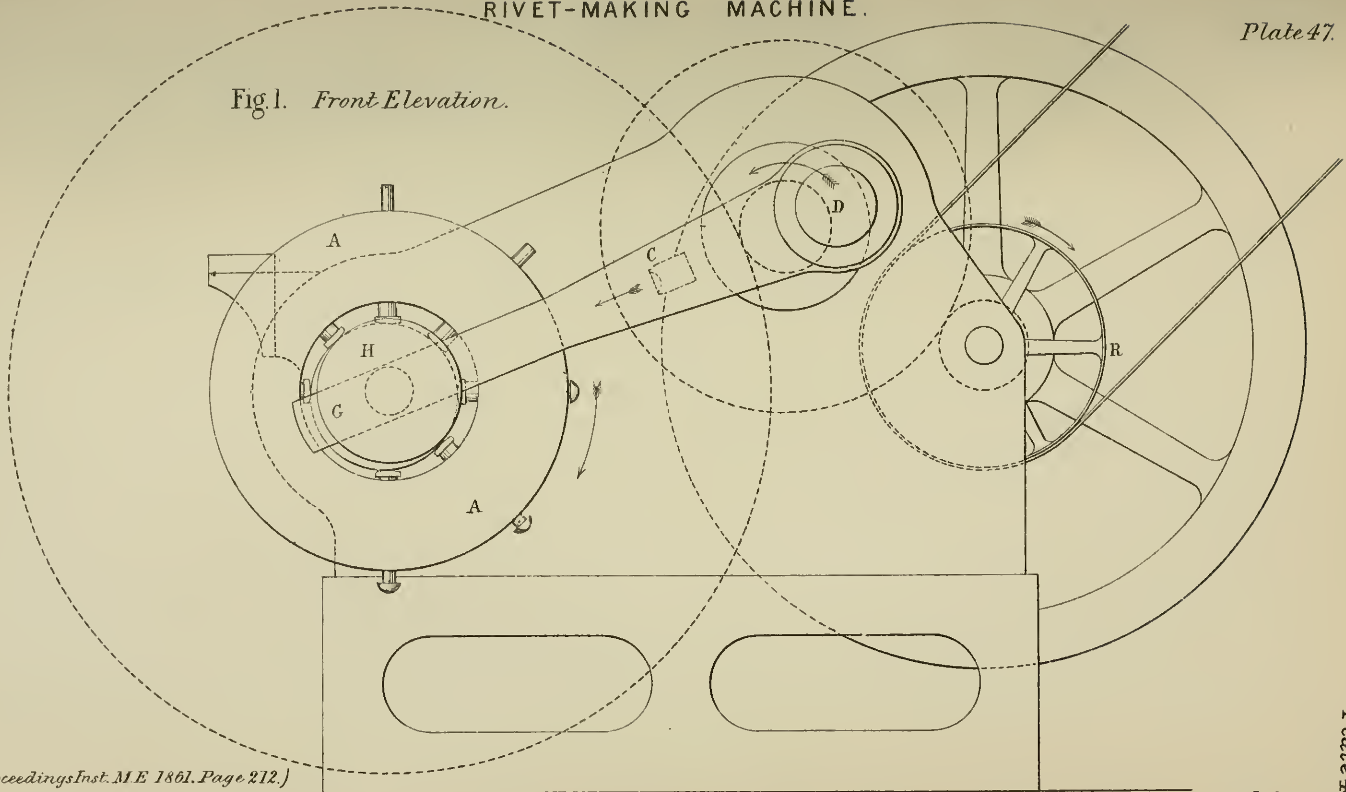
Fig. 9. *Section of Bottom Wedging Crib.*

(Proceedings Inst. M. E. 1861. Page 193.)

Scale 1/10th.

RIVET-MAKING MACHINE.

Fig. 1. *Front Elevation.*



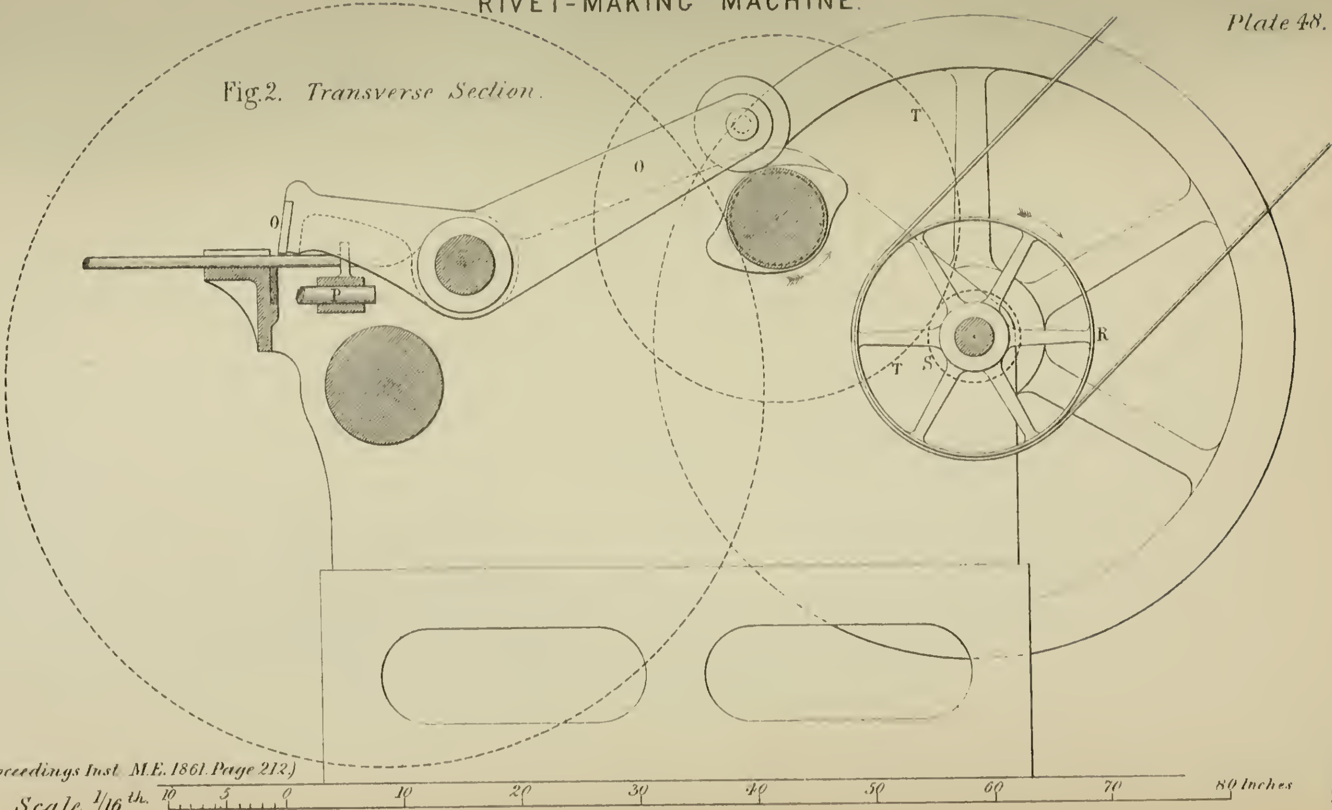
(*Proceedings Inst. M.E. 1861. Page 212.*)

Scale 1/16th. 10 5 0 10 20 30 40 50 60 70 80 *Inches.*

Plate 47.

RIVET-MAKING MACHINE.

Fig. 2. *Transverse Section.*

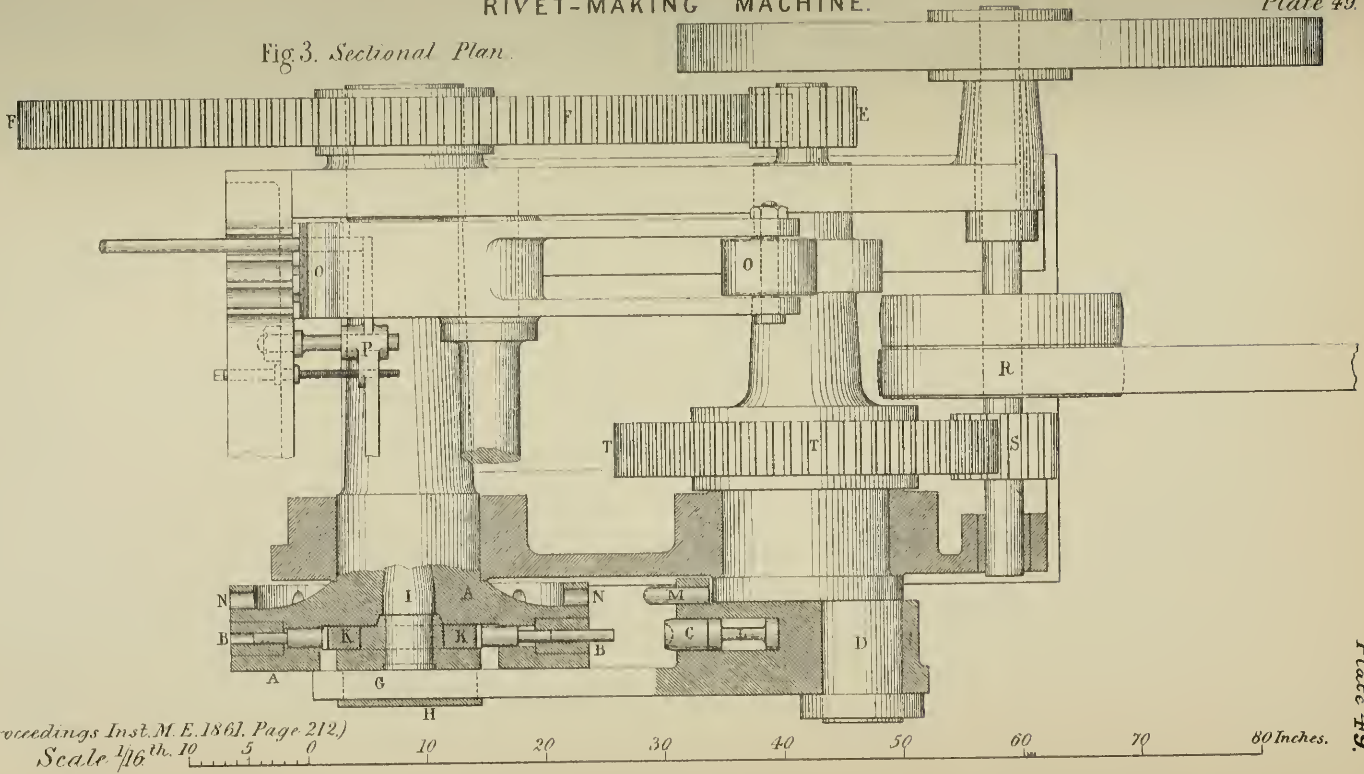


(Proceedings Inst. M.E. 1861. Page 212.)

Plate 48.

RIVET-MAKING MACHINE.

Fig. 3. *Sectional Plan.*



(Proceedings Inst. M. E. 1861, Page 212.)

Plate 49.

RIVET-MAKING MACHINE.

Fig. 4. *Side Elevation.*

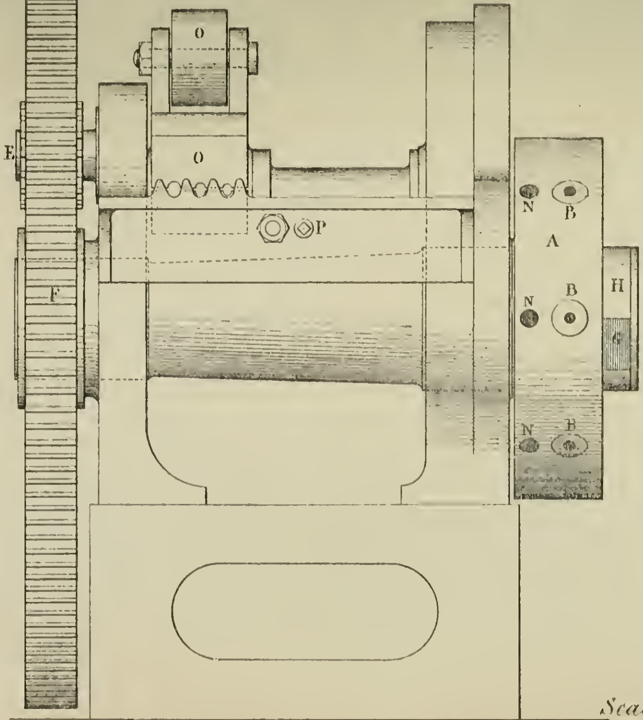
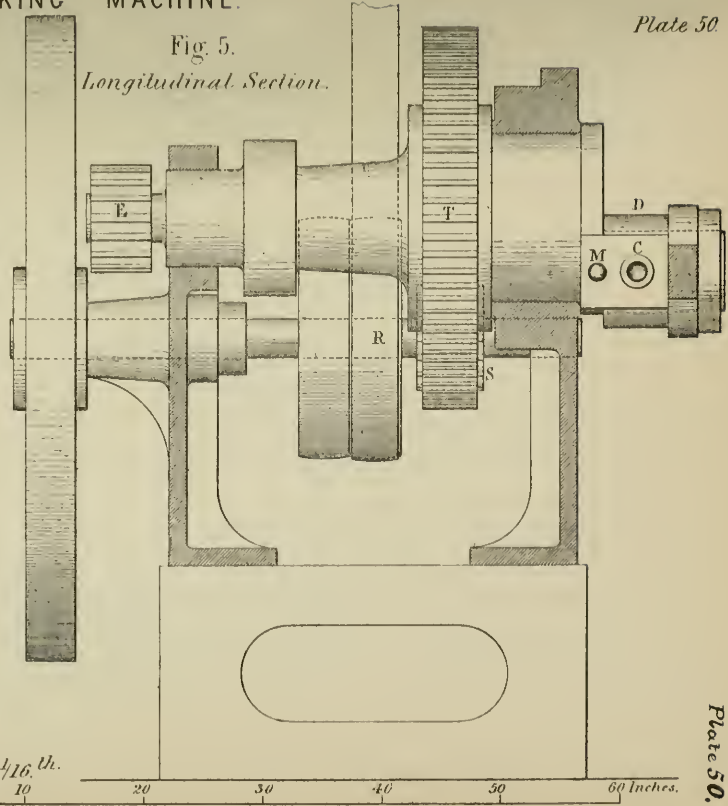


Fig. 5. *Longitudinal Section.*

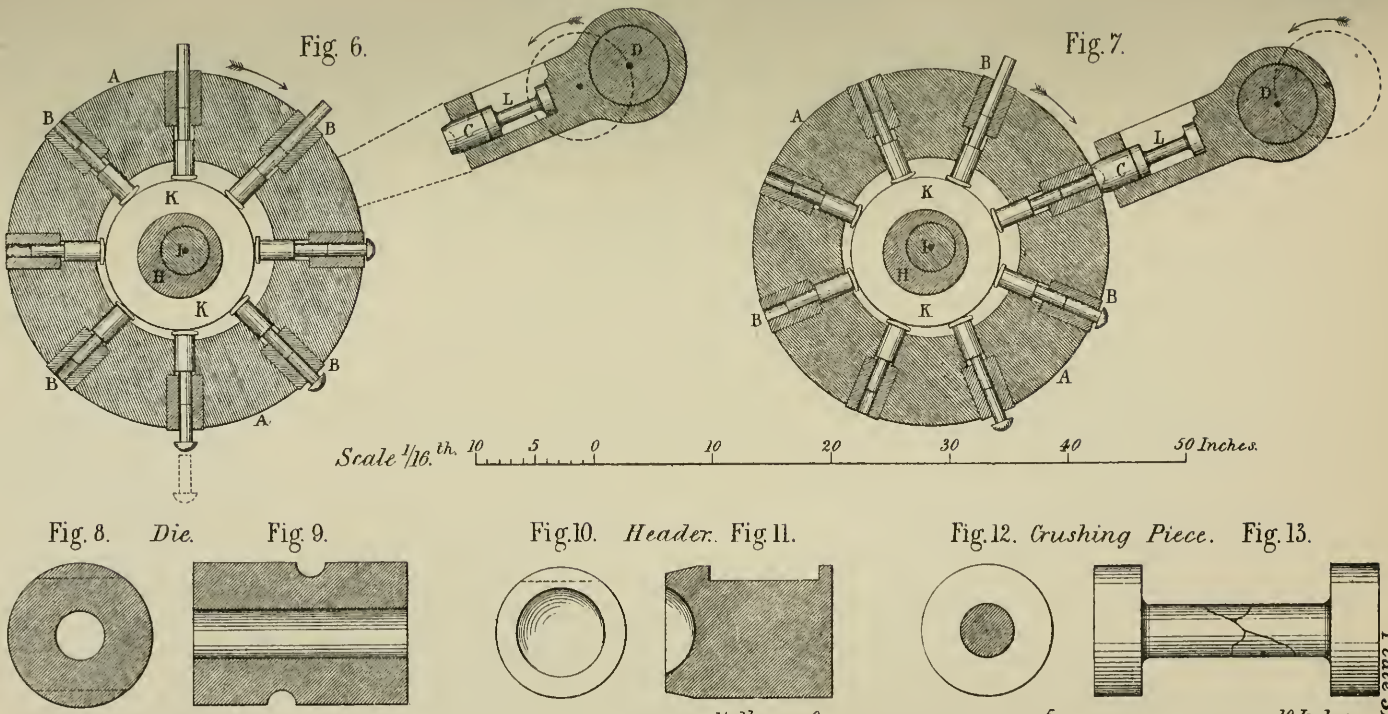


Scale 1/16th.

(Proceedings Inst. M.E. 1861. Page 212.)

Plate 50.

RIVET-MAKING MACHINE.



(Proceedings Inst. M.E. 1861. Page 212.)

ELEVATOR FOR COLLIERY DRAINAGE.

Fig. 1. *General Plan of Colliery.*

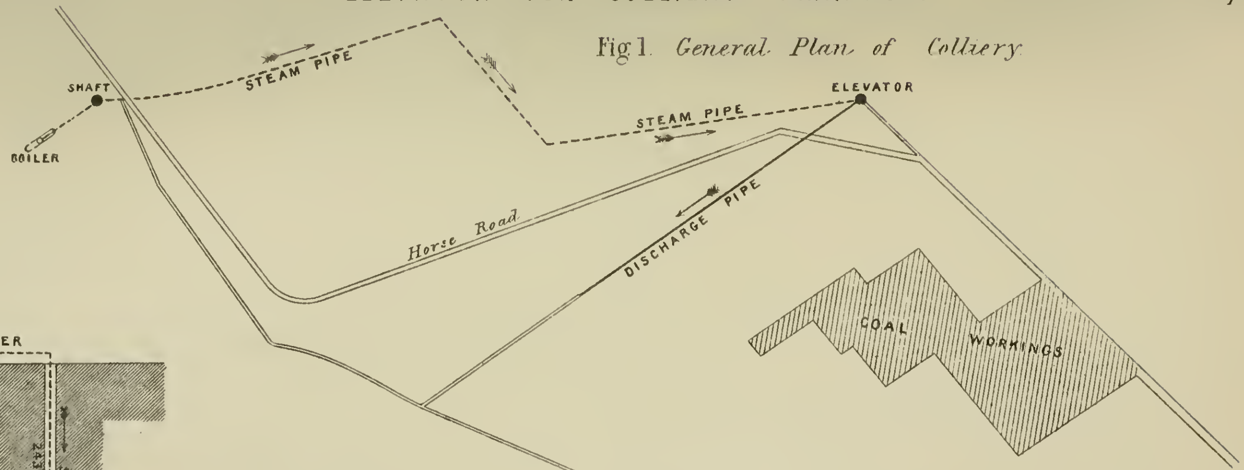
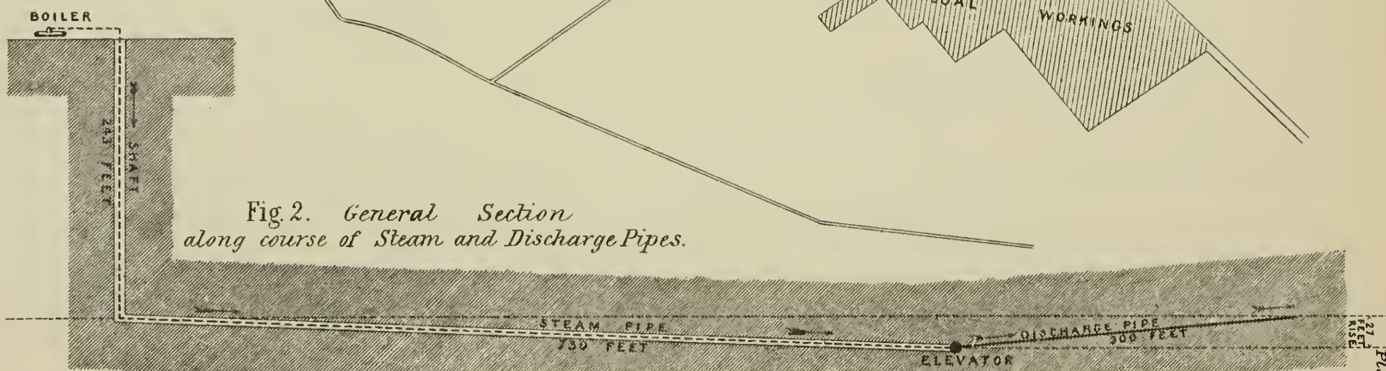


Fig. 2. *General Section along course of Steam and Discharge Pipes.*



(Proceedings Inst. M.E. 1861. Page 220.)

Scale 1/2000th. 0 50 100 200 300 400 500 600 700 800 900 1000 Feet.

ELEVATOR FOR COLLIERY DRAINAGE. *Plate 53.*

Fig. 3. *Arrangement of Elevator in pit.*

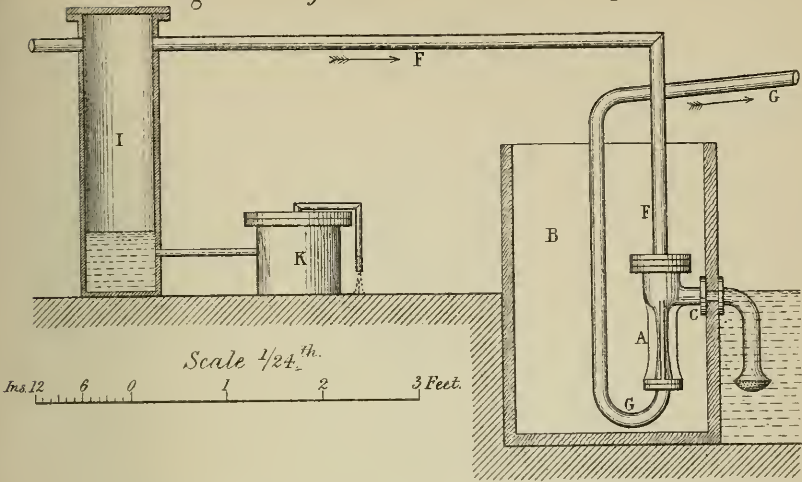
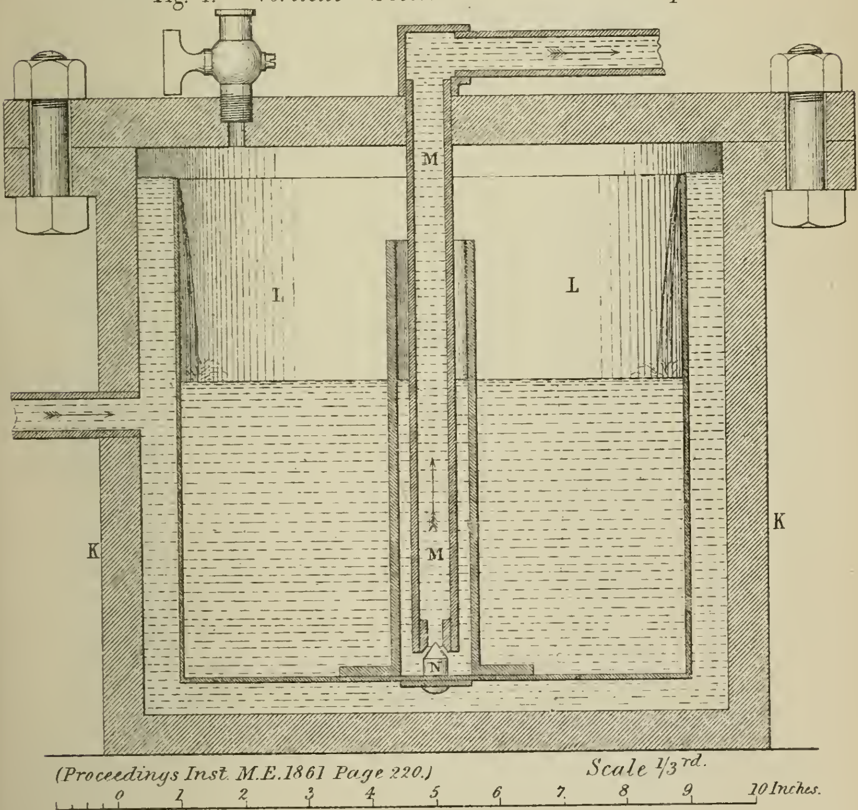


Fig. 4. *Vertical Section of Water Trap.*



(Proceedings Inst. M.E. 1861 Page 220.)

Plate 54.

Fig. 5. *Vertical Section of Elevator.*

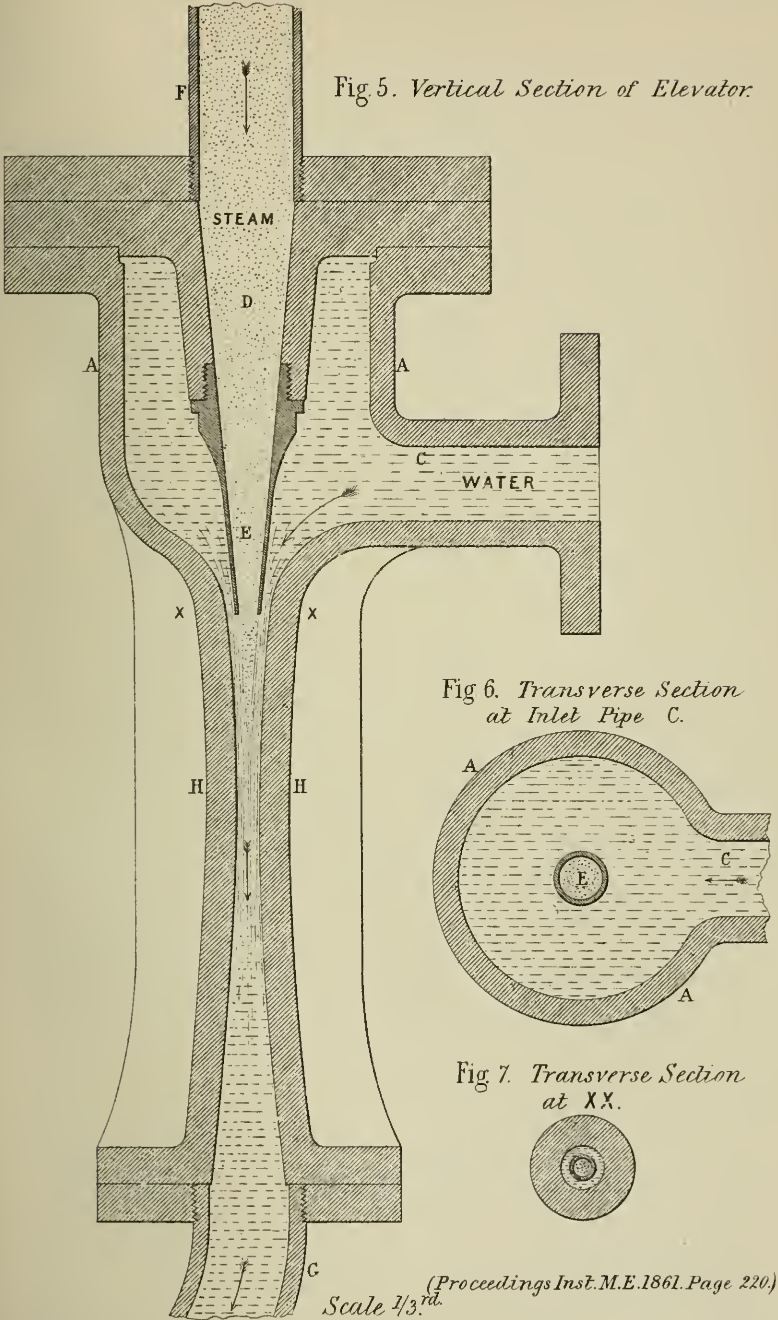


Fig 6. *Transverse Section at Inlet Pipe C.*

Fig 7. *Transverse Section at XX.*

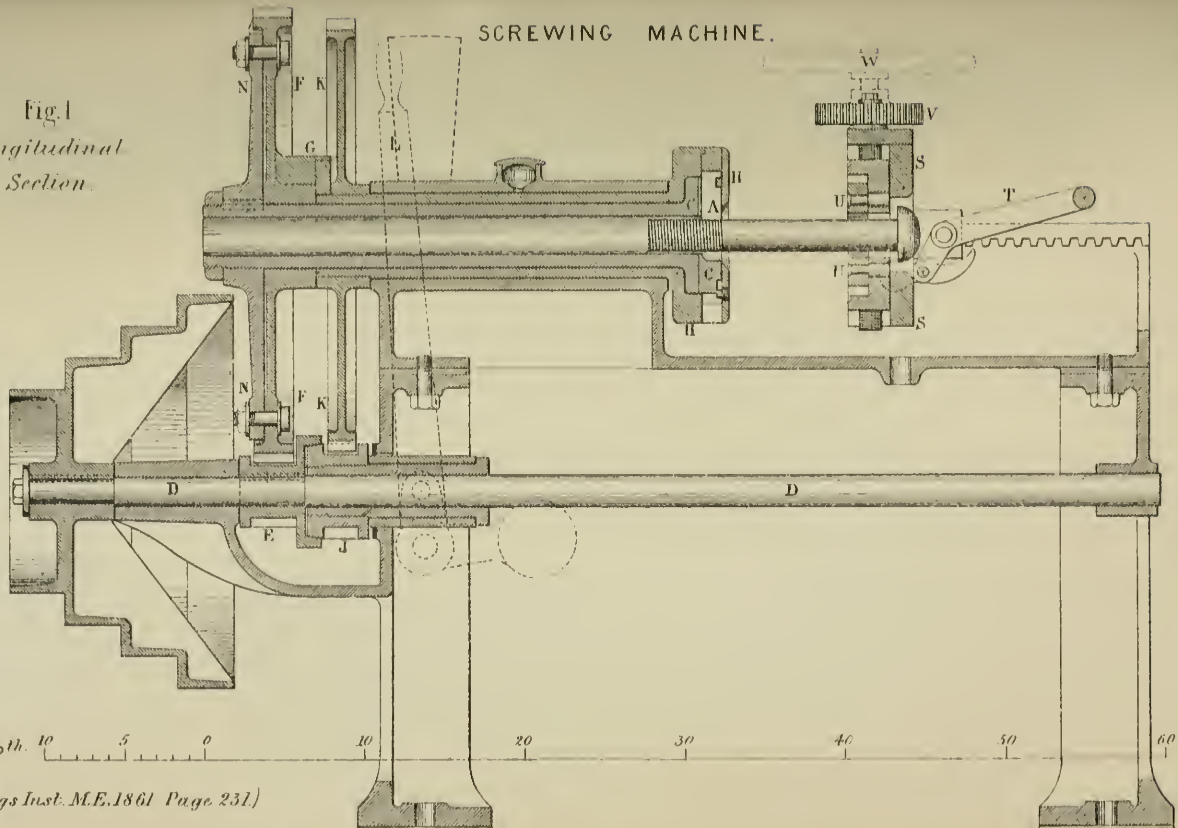
(Proceedings Inst. M.E. 1861. Page 220.)

Scale 1/3rd.

0 1 2 3 4 5 6 7 8 9 10 *Inches.*

SCREWING MACHINE.

Fig. 1
Longitudinal Section.

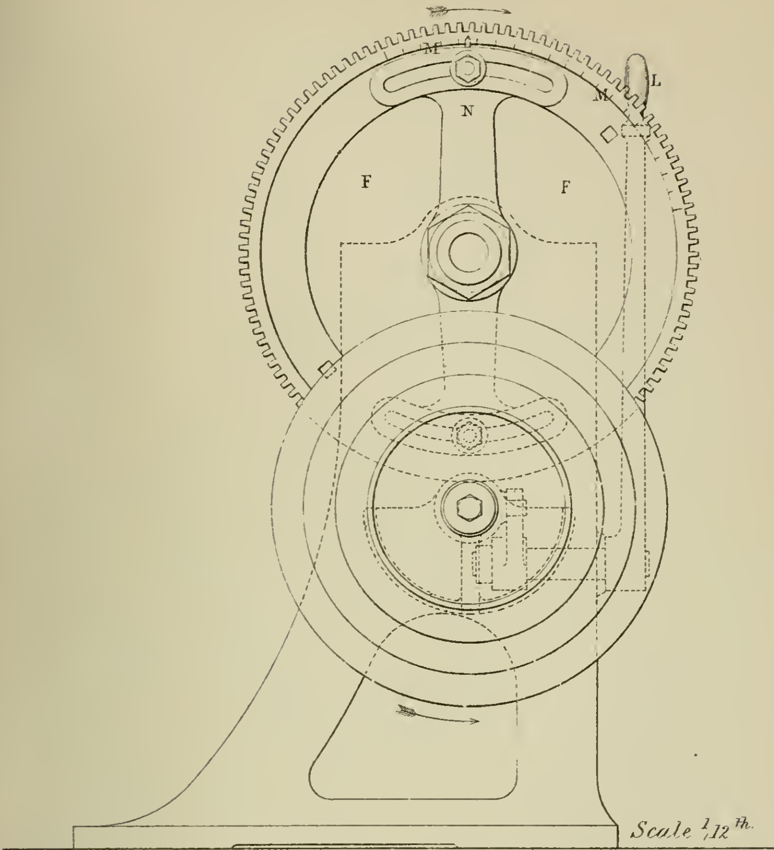


Scale 1/12th.

(Proceedings Inst. M.E. 1861 Page 231.)

Plate 56.

Fig. 2. *End Elevation.*



Scale 1/12th.

Fig. 4.
Holding Clamps.
Scale 1/6th.

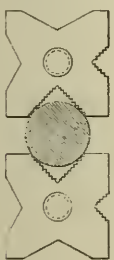
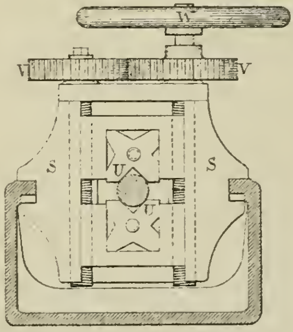
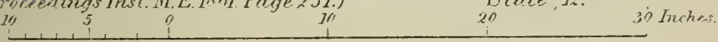


Fig. 3. *Elevation of Sliding Holder.*



(Proceedings Inst. M.E. 1861. Page 231.)

Scale 1/12th.



SCREWING MACHINE.

Fig 5. *Longitudinal Section of Die Box.*

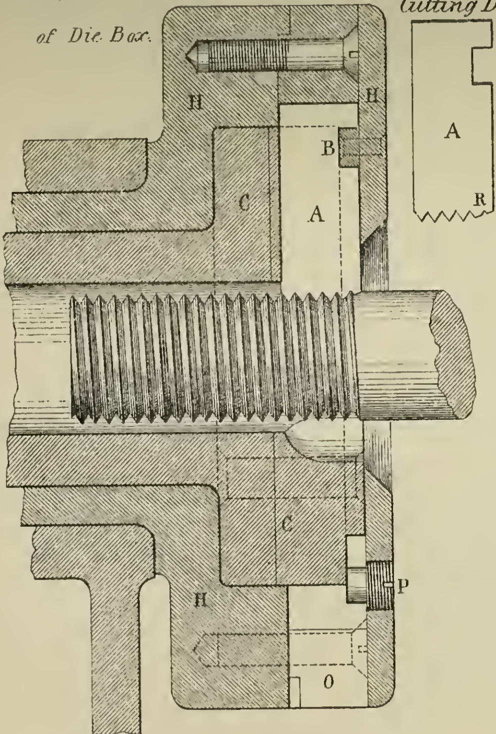


Fig. 7. *Cutting Die.*

Fig. 6. *Front Elevation of Die Box with cover plate removed.*

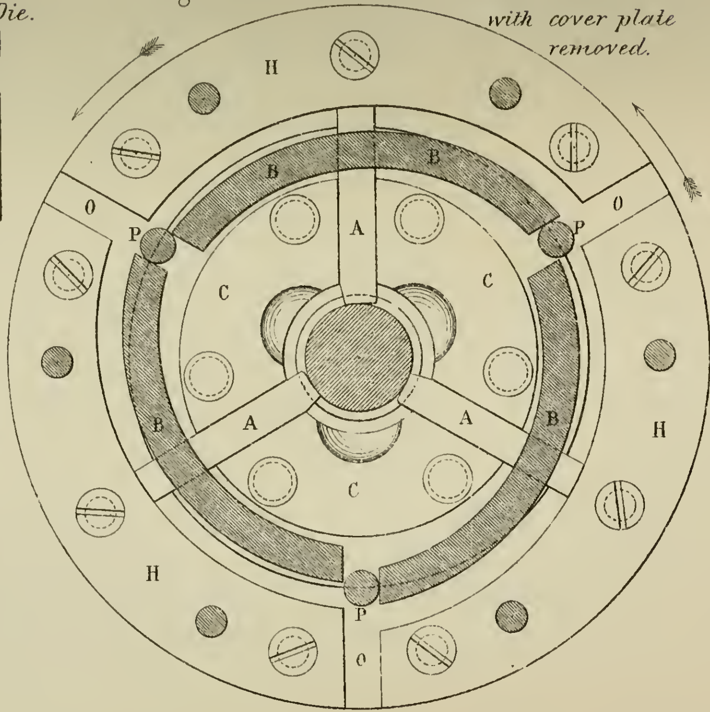
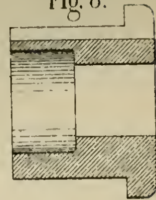
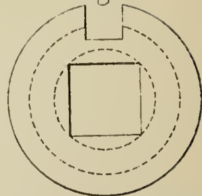


Fig. 8.



Tap Holder
Fig. 9.



Key for fixing Tap Holder.
Fig. 10.

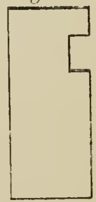


Fig. 11.

Scale 1/3rd.

(Proceedings Inst. M. E. 1861. Page 231.)

PROCEEDINGS.

7 November, 1861.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 7th November, 1861; Sampson Lloyd, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman referred to the success of the Annual Provincial Meeting held at Sheffield in the summer, with which the members who were present had been much gratified; they had been much interested in the sight of the principal works which were so liberally thrown open for their inspection, with special arrangements for showing the operations on a large scale. The members were most handsomely received and entertained by the Local Committee, who made great exertions to give them a hearty reception on the occasion.

The Chairman announced that the President, Vice-Presidents, and five members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting:—

PRESIDENT.

SIR WILLIAM G. ARMSTRONG,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

(Six of the number to be elected.)

ALEXANDER B. COCHRANE,	Dudley.
EDWARD A. COWPER,	London.
JAMES FENTON,	Low Moor.
BENJAMIN FOTHERGILL,	London.
SAMPSON LLOYD,	Wednesbury.
HENRY MAUDSLAY,	London.
JOHN PENN,	London.
JOHN RAMSBOTTOM,	Crewe.
J. SCOTT RUSSELL,	London.
C. WILLIAM SIEMENS,	London.
JOSEPH WHITWORTH,	Manchester.
NICHOLAS WOOD,	Hetton.

COUNCIL.

(Five of the number to be elected.)

ALEXANDER ALLAN,	Perth.
FREDERICK J. BRAMWELL,	London.
WILLIAM E. CARRETT,	Leeds.
GILBERT HAMILTON,	Soho.
GEORGE HARRISON,	Birkenhead.
THOMAS HAWKSLEY,	London.
EDWARD JONES,	Wednesbury.
JAMES SAMUEL,	London.
CHARLES P. STEWART,	Manchester.
EDWARD WILSON,	Worcester.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Charles Edwards Amos,	London.
Thomas Dixon,	Low Moor.
Thomas Fearnley,	Bradford.
Joshua Field, Jun.,	London.
William Bailey Hawkins,	Pontypool.
Samuel Waite Johnson,	Manchester.
Gustavus Natorp,	Sheffield.
John William Naylor,	Leeds.
Walter Henry Scott,	Wolverton.
John Shepherd,	Leeds.
George Taylor,	Leeds.
Robinson Thwaites,	Bradford.
William Yule,	St. Petersburg.

GRADUATE.

Henry Charles Middleton,	Birmingham.

The following paper was then read :—

DESCRIPTION OF A RIVET-MAKING MACHINE.

By Mr. CHARLES DE BERGUE, of Manchester.

The main feature of this machine consists in its making rivets by a continuous motion, and in its compactness and simplicity of action. The construction of the machine is shown in Plates 47 to 51. Fig. 1, Plate 47, is a front elevation of the machine, showing only the heading arrangement. Fig. 2, Plate 48, is a transverse section, showing the cutter for cutting the blanks previous to heading. Fig. 3, Plate 49, is a sectional plan. Fig. 4, Plate 50, is a side elevation; and Fig. 5, a longitudinal section.

The disc A, Fig. 1, Plate 47, revolving on a horizontal shaft carries the dies for holding the blanks to form the rivets, of which there are eight in the circumference, marked BB in Figs. 6 and 7, Plate 51, revolving in the direction of the arrow. Figs. 8 and 9 show enlarged sections of the dies. The cast iron header C, shown enlarged in Figs. 10 and 11, by which the heads of the rivets are formed, is carried by the crank D fixed on a second horizontal shaft, revolving eight times for once of the disc A, and so geared with it by the toothed wheels EF, Fig. 3, as to coincide exactly with the eight dies as they successively pass before the header C at the moment of its full stroke towards the disc. At this time the disc carrying the dies and the header are for a moment travelling together. The end of the bar carrying the header C slides in a slot G in the ring H, which revolves freely upon the centre pin I of the disc. The inner half of this ring H is turned eccentrically, as shown in Figs. 6 and 7; and upon it a loose ring K is placed, which takes the thrust of the pins for holding up the rivets during the heading and forcing them out of the dies when completed. The eccentric is held in a fixed position, or nearly so, by the end of the header bar sliding through the slot G,

the eccentricity being set not quite opposite to the point where the heading takes place, so that the moment the header has left the die, the eccentric begins to act in forcing the rivet out. The loose ring K always moves with the pin which holds up the rivet, while the heading is being performed and also while forcing out the rivet, and thus throws the wear upon the whole surface of the eccentric, instead of confining it to the portion directly under the header.

To prevent the possibility of accident to the machine from blanks being put into the dies too cold or too large in size, the header C is supported behind by a small crushing piece of cast iron L, shown enlarged in Figs. 12 and 13, Plate 51, which lies free in a recess in the header bar. This crushing piece is made of such sectional area as to resist the usual crushing strain required for heading a rivet, but to yield by crushing if by any accident a cold rivet blank or any other unyielding substance should get between the header and the die, forming a complete protection against injury of the machine by overstrain in working. Fig. 13 shows the manner of fracture of one of the crushing pieces.

During the time of the header being in action, the motion of the header and the die as governed by the toothed wheels E and F would not be perfectly coincident, except at the beginning and the end of the heading process. At the point where the process commences, which is a point adjustable at option, the centre line of the header as carried forward by the toothed wheels coincides with the centre line of the rivet to be headed; then proceeding in the direction of the rotation, the rivet over-runs the header slightly, and again exactly coincides with it when on the centre line or line of greatest pressure: after which the reverse action takes place as the header recedes from the die. The motions of the header and the die are however made perfectly coincident throughout by means of a steel pin M, Fig. 3, Plate 49, inserted in the header bar alongside of the header; and eight corresponding holes N to receive this pin are bored in the circumference of the disc, Figs. 3 and 4, side by side with the holes which contain the dies. The pin M enters the hole in the disc at the point where the heading process commences; and the teeth of the driving

pinion E are at the same time partially cut away, so as to clear the teeth of the larger wheel F while the pin is in action; and then as the pin leaves the hole in the disc, the teeth of the pinion again take up the driving action and continue the movement of the disc. Thus the die is carried forward during the heading process by the pin M, independently of the teeth of the pinion, which are not required at that part of the rotation for working the machine; but they are still retained in order to keep the wheels in gear throughout the entire revolution, and are left strong enough to carry on the motion safely even without the pin M.

The bars for making the rivets are heated in a furnace alongside the machine, and are then cut off to the required lengths by a lever cutter O, Fig. 2, Plate 48, driven by a double cam on the heading shaft, thus allowing two lots of rivets to be cut for one rivet made, and so giving time for changing the bars while still a sufficient supply of blanks is always kept cut; 4 to 6 blanks are cut off in each batch, about 10 bars being kept in the furnace at once. The blanks are fed into the dies by two boys, a third boy doing the cutting. The lengths to be cut off are regulated by an adjustable bar P, Fig. 2, sliding upon a pin and moved backwards or forwards by a screw.

The first motion is given to the machine by a belt upon the pulley R, Fig. 3, Plate 49, and thence through the pinion S and spur wheel T. The framing at the front of the machine is made exceedingly strong, for resisting the strain of tension thrown upon it during heading; while the back frame on the contrary is arranged to receive the compression strain of the tail ends of the shafts.

The machine is placed close by the side of the furnace, so that the heated bars have only to be carried about 2 feet distance from the furnace mouth to the cutter, and the ends cut off fall into a trough, down which they run to a convenient position for the boys who feed the dies. The finished rivets fall out below the disc into a truck placed to catch them, and are thence wheeled away. The machine is speeded according to the size of rivets to be made: thus for 1 inch rivets the disc revolves 4 times per minute, making 32 rivets per minute; and for $\frac{1}{2}$ inch rivets the disc revolves 5 times per minute, making 40 rivets per minute.

The objects aimed at in applying machinery to rivet making are, more uniform and perfect manufacture of the rivets, and a more rapid production than by hand making; together with independence of the risks of delay in the supply by hand work when large quantities are required. But from the simple nature of the work, and the small margin for economy in manufacture by the application of machinery, only a very simple and durable machine is suitable for the purpose.

The advantages found in the machine now described are that by the continuous motion a saving of time is effected, and a larger quantity of rivets are produced in a given time; while the shocks and concussions attendant upon stopping and starting the motion, with the consequent jar and destructive wear and tear, are avoided, increasing the durability of the working parts. The use of the crushing piece also behind the header serves as an effectual safeguard against breakage, and prevents the strain that can be put upon the machine ever exceeding the intended limit, which for making 1 inch rivets is taken at about 20 tons. The whole machine also lies in a compact and convenient form, taking up a space of about 5 feet by $9\frac{1}{2}$ feet, as shown in the plan, Fig. 3, Plate 49; and only about 8 feet by $9\frac{1}{2}$ feet total space including the heating furnace.

The heating furnace is of a compact and convenient construction, 3 feet long by $2\frac{1}{2}$ feet wide in the body, with the fire at the back end. The flame passes over the bars to be heated, and down a flue at the front end, just within the drawing-out door, thus avoiding any cooling effect upon the bars when the door is opened, and keeping up a very uniform heat.

Mr. Joy showed specimens of the rivets of different sizes made by the machine, and of the heading dies both new and when worn out; also of the safety crushing pieces, whole and broken.

The Chairman observed that there were many difficulties to be overcome in applying machinery satisfactorily to the manufacture of rivets, and though several machines had been constructed for the

purpose, few had proved durable in the working parts or perfect in the mode of making the rivets. The present machine though not new in some of its parts appeared in others to present novelties deserving of consideration. He enquired how long the machine had been in operation, and what had been the wear and tear of the working parts, as that was the main point in all such machines, which would often work well for a time, but afterwards were always getting out of repair and requiring renewal.

Mr. Joy replied that they had had two machines at work for about two years, and a larger machine as shown in the drawings for about one year. No wear was yet perceptible on the working parts, excepting the dies and headers, which of course had to be renewed for both hand and machine work in proportion to the amount of work done. The two horizontal shafts in the machine had been taken out and examined, and were found entirely free from wear. The bearings and shafts were entirely cast iron, got up very true, and with such a large extent of surface that the pressure was never enough to begin wearing the metal. When the first machine was made, a heart-wheel or cam was employed for pushing the rivets out of the dies; but the ends of the jingle pins grinding against it under the heavy pressure of forcing out the rivets caused such an excessive wear at that part that after a short time the cam had to be taken out for repair, and they had turned it down circular as an eccentric, and put on a loose ring as a ready means of repairing it. This had proved so entirely successful in removing the wear that it had been permanently adopted in the machines; the head of the pin seized the surface of the ring under the severe pressure of forcing out the rivet, and carried the ring round with it, so that there was no wear between the head of the jingle pin and the ring, while the large surface of the eccentric allowed the ring to slip round it freely without sensible wear. The cast iron crushing piece behind the header gave way occasionally with a sharp report in the ordinary course of working, particularly on first starting, before the machine got warmed into its usual working condition, the hot blanks probably being too much chilled in the cold dies; but a supply of crushing pieces was kept on hand and a fresh one put in whenever required.

The CHAIRMAN asked how long the cast iron dies lasted, and whether they were chilled in casting, or were simply plain castings.

Mr. JOY replied that the dies usually lasted two or three days and sometimes as much as six days. The cast iron was toughened by a mixture of wrought iron scrap, and the dies were merely cast in sand and not chilled ; the die hole was drilled afterwards out of the solid, and a groove was slotted in the side of the die to receive the tightening key for holding it in the disc, but no fitting was required for fixing the dies in their places. They had tried casting the hole in the die by means of a hollow steel spindle with water running through it, so as to chill the interior of the hole ; but this did not succeed at all, and a sand core had also been tried, which was more nearly successful ; the simplest and best way however was to cast the die solid and drill the hole afterwards. After being worn out for one size, the dies were bored out again several times for larger sizes of rivets, before being completely worn out. The header was also made of cast iron, not chilled : cast iron was found to stand better than steel for the header, for a steel header had been tried but it cracked all to pieces after heading a few rivets, and steel was of no use for such purposes.

Mr. E. A. COWPER had also found cast iron stand best for a similar purpose in a large hydraulic punching press for punching out red-hot the links for suspension bridges : a link $7\frac{1}{2}$ feet long and 1 foot 8 inches across the eye was punched out of 1 inch thickness of metal by a cast iron punch and die, when the metal was red-hot. He had tried steel punches also, but they did not stand for punching more than half a dozen links and were then spoilt, as the steel would not stand the frequent heating by contact with the hot iron without cracking. Ultimately cast iron punches and dies alone were used, and lasted each about a month in punching out the links, punching in that time probably 200 links. He enquired whether there was any circulation of water in the rivet machine for keeping the dies cool when at work.

Mr. JOY replied that there was no circulation of water in the dies, but two streams of water played over the disc as it revolved to keep it cool ; it must not be too much cooled however, otherwise the machine did not work well, and the crushing piece got broken frequently ; the

machine was allowed to get about as hot as the hand could bear, and then it worked well.

Mr. E. A. Cowper enquired whether any of the machine rivets had been cut down longitudinally through the centre, and the surface then polished and browned with acid, to show the direction of the fibre in the rivet head. In hand-made rivets the smith first jumped up the end of the blank, thereby spreading over the fibre all round, before shaping the head; and he thought the fibre might be rather better laid over in that way than in the machine rivets. He asked whether the comparative strength of the machine rivets and those made by hand had been ascertained.

Mr. Joy had not tried the comparative strength of the machine made rivets, nor examined the section in the manner suggested for showing the fibre; but as a means of showing plainly each stage of the heading process he had tried in the machine a series of blanks too short to make the rivet, increasing successively in length up to the full size. This experiment showed that the iron was first bulged out all round close to the die, as soon as the header began to press upon it; and this bulging out gradually increased in extent as the length of the blank was increased, so that in the complete rivet the head was made by the fibres of the iron being bent over all round, and had therefore great strength and solidity. This was further shown by tearing off some of the rivet heads, when the fibre of the iron was found to be all broken through transversely, in consequence of the direction it had assumed by being bent over to form the head. The great advantage in making rivets by machinery was that they were all exactly alike; and this uniformity was effectually attained in the present machine, and could not be secured except by the use of machinery.

Mr. E. Jones thought the strength of rivets depended mainly on the quality of iron they were made from, and that there was not much difference in strength between hand and machine made rivets from the same quality of iron, if equal care were taken in the manufacture.

The Chairman asked what was the relative cost of production in making rivets by the machine and by hand, and the capability of the machine as to extent of manufacture.

Mr. Joy replied that the relative cost of making the rivets depended mainly on the total quantity to be made: if only a small quantity were wanted, hand work was undoubtedly much the cheapest; but if a large quantity, then the machine would be the cheapest. The number of rivets made per day by the machine depended much on the form of the head: an ordinary snap or semicircular head was the best to make, but full large heads with flat tops were most difficult, requiring so much material to be crushed up to form the head; and some $\frac{3}{4}$ inch rivets that they had made with large heads took as much as $2\frac{1}{2}$ inches length of body to make the head. Any form or size of head however could be made in the machine by simply changing the header for one of the required shape. The number of rivets made per day by the present machine in regular work was about as follows:—

$\frac{7}{8}$ inch rivets	3 inches long	when finished,	30 cwts.	or	4000	rivets per day
$\frac{3}{4}$ „	3 „	„	25 „		6500	„
$\frac{5}{8}$ „	$2\frac{1}{2}$ „	„	20 „		9000	„
$\frac{1}{2}$ „	$2\frac{1}{2}$ „	„	15 „		12000	„

The Chairman enquired what was the cost of the machine.

Mr. Joy said a machine of the size shown in the drawings cost about £300, including an apparatus for moulding and casting the dies.

The Chairman moved a vote of thanks to Mr. De Bergue and Mr. Joy for the paper, which was passed.

The following paper was then read:—

ON AN APPLICATION OF GIFFARD'S INJECTOR AS AN ELEVATOR FOR THE DRAINAGE OF COLLIERY WORKINGS.

By Mr. CHARLES W. WARDLE, of Leeds.

The apparatus described in the present paper was applied by the writer to meet the special requirements of the working of a portion of the Kippax Colliery near Leeds, where it has been in constant operation for the last eight months. It is a self-acting apparatus for raising the water for drainage of a portion of the pit workings, and has completely answered its intended purpose; and a similar application may be of service in other special cases where the cost of fuel is not a consideration, but a simple and inexpensive apparatus is required not needing attendance in working. In the present case a small portion of the colliery, about 2 acres, was required to be worked out, which was lying below the drainage level of the pit, and at a considerable distance from the shaft; and as the extent to be worked was so limited, it did not allow of the erection of a special pumping engine, and hand pumping was employed to raise the water a height of 27 feet to the upper level which was drained by an engine. This mode of draining was continued for two years, two shifts of two men each being employed constantly at the last with a $3\frac{1}{2}$ inch pump; but they were not able to keep down the water in the lower workings as it had increased in quantity, and some other less expensive and more efficient means was required to enable the rest of the coal to be worked out.

An application of a Giffard's injector as an Elevator was proposed by the writer for this purpose, and was carried out as shown in Plates 52, 53, and 54. Fig. 1, Plate 52, shows a general plan of the colliery, with the position of the elevator and the steam and discharge pipes; and Fig. 2 is a general section taken along the line of the steam and discharge pipes. The steam pipe, shown by the dotted

black line, is a wrought iron pipe of $1\frac{1}{2}$ inches bore with screwed joints, carried 60 feet from the steam boiler to the shaft, descending the shaft 243 feet, and then passing along an inclined heading 730 feet long and falling 27 feet to the elevator, which takes the water at that level and discharges it by an iron pipe of 2 inches bore, shown by the full black line, carried a distance of 300 feet up another inclined heading to the main drainage level at a height of 27 feet above.

The elevator A, Fig. 3, Plate 53, is fixed in a cistern B sunk in the water, so that the inlet pipe C is at the water level. The elevator is shown in section one third full size in Figs. 5 to 7, Plate 54, and is a modification of a small sized injector, made in the simplest form for the sake of cheapness. It consists of a fixed steam jet D, with brass nozzle E of $\frac{5}{16}$ inch aperture, fixed in a cast iron casing A without any means of altering the position, with the steam pipe F connected at the top and the discharge pipe G at the bottom, the whole being closed without any overflow; the discharge aperture of the casing A is tapered gradually in both directions to $\frac{3}{8}$ inch bore at the throat H.

In consequence of the great length of the supply steam pipe, 1030 feet from the boiler to the elevator, provision has to be made for constantly carrying off the condensed water deposited in the pipe, in order to ensure the elevator being constantly supplied with tolerably dry steam, as the entrance of water with the steam would stop its action. This is effected by passing the steam through the top of the depositing box I, Fig. 3, Plate 53, 10 inches diameter and 3 feet deep, from the side of which the water flows off into the self-acting water trap K, shown in section one third full size in Fig. 4. The water trap is a closed cylinder containing a copper cylindrical float L, 8 inches diameter and 8 inches deep, open at the top, and guided by a centre tube sliding up the small pipe M. This pipe M is prolonged outside over the side of the vessel K, and serves as the discharge for the accumulated water; its lower end is closed by a small conical valve N fixed on the bottom of the copper float, which keeps it closed until the water has accumulated in the trap outside the copper float so much as to flow

over its sides at the top, and to fill up the interior of the float so that it is overweighted and sinks; the conical valve N being then opened, the water contained in the float is expelled through the discharge pipe M by the pressure of steam upon its surface, and the float again rises and closes the pipe ready for another charge.

The temperature of the heading through which the steam pipe is carried is about 72° Fahr., and the steam pipe is clothed for about one third of its length, throughout the portion from the boiler to the bottom of the shaft, with a coating of tarred felt wrapped round it, and the remaining portion in the pit is wrapped with haybands. But with the great length of the pipe, 1030 feet, and its small diameter of $1\frac{1}{2}$ inches, this clothing is not sufficient to prevent a very considerable amount of condensation taking place; and there is a constant discharge from the water trap of about 3 gallons per hour during the working of the elevator, a discharge taking place at successive intervals of about a quarter of an hour. This serves quite efficiently for keeping the steam supplied to the elevator free from water, and the elevator continues working uninterruptedly for many hours together; when the supply of drainage water is sufficient, it works continuously day and night without any stoppage. It does not require any attention in working, and is started simply by turning on the steam at the boiler at top, when the elevator starts working at once. There is no valve in the discharge pipe, so that the pipe becomes emptied each time that the elevator is stopped working, the water running back through the instrument and out at the inlet pipe. There is consequently no pressure of water to be overcome at starting, and the elevator always starts working at once, when the supply water is up to the level of the inlet, but not if the water has to be lifted in the inlet pipe. All that is required in starting the elevator afresh is to blow through by turning on the steam for two or three minutes to warm the pipes; and then after shutting off the steam for a few seconds to allow the condensed water to drain off, the apparatus is started at once in full work by turning on the steam again.

When the apparatus was first set to work, the depositing box had not been applied, and the action of the elevator became soon stopped by an accumulation of rusted scales from the interior surface of the

wrought iron steam pipe. But the addition of the depositing box completely removed this difficulty, and the box has never required opening during the eight months it has been in work.

The pressure of steam at which the elevator is regularly worked is 34 lbs. per square inch above the atmosphere at the instrument, and it will keep working down to about 28 lbs. pressure when it stops. A difference of pressure of 13 lbs. per inch constantly exists between the two ends of the steam pipe, the working pressure in the boiler being 47 lbs. per square inch, in consequence of the large condensation in the pipe and the resistance occasioned by its small diameter. The elevator accordingly stops working when the boiler pressure is lowered to about 40 lbs. per inch.

The temperature of the delivery water at the further end of the discharge pipe is 94°, that of the supply water being 58°; and the quantity discharged by the elevator is 780 gallons per hour raised a height of 27 feet. The consumption of rough coal slack for generating the steam supplied is about $1\frac{1}{2}$ cwt. per hour; the boiler is a plain cylindrical one, 4 feet diameter and 30 feet long, with oven setting, and supplies steam also to the winding engine for the pit; but its consumption of fuel was taken separately in the night when supplying steam to the elevator alone, the fuel being only refuse slack from the pit of a very inferior and dirty description, for which there is no other use. Consequently the only expense incurred in the drainage of the workings by the elevator, besides the little extra wear of the boiler, is the cost of attendance for firing the boiler about once per hour during the night, when the winding engine is not required to be worked. There have been no expenses for repairs of the apparatus, the elevator never having been opened since first put in its place, except on the occasion previous to adding the depositing box soon after starting, as before mentioned.

The following are some of the cases where the elevator seems to be applicable with advantage. Where fuel is very cheap: as at a pit's mouth, where the small coal is sometimes burnt simply to get rid of it. Where steam is blowing to waste: as in forges at night, when the

production of steam continues without occasion for its use to the same extent as in the day, and often its blowing off at night is a nuisance; this application of the elevator has been made at Messrs. Sharp Stewart and Co's. works at Manchester, to fill up the tanks during the night for the day's supply, by making use of the waste steam previously thrown away. Where warm water is of value in the top cistern: as in the case of railway tanks and some factory purposes. Where the supply is seldom needed, and it is desired to save the first cost and maintenance of a pumping engine and also the attendance of an engineman. Where absolute certainty of having the water lifted is required, over and above all considerations of expense: as in keeping the tuyeres of a blast furnace cool; Messrs. Schneider Hannay and Co., of the Ulverstone Hæmatite Iron Works, are arranging to attach elevators to supply the cisterns that furnish the water to the tuyeres of their blast furnaces, being unwilling to depend on their pumps which sometimes fail, whereas the elevator never fails; in this instance also there is an abundance of steam raised by the heat of the waste gas. Where frosts prevail and pumps suffer from ice: the elevator, like the injector, gets itself into working order upon the admission of steam, even when the whole instrument is a mass of ice, the heat of the steam gradually thawing the entire mass without the possibility of doing harm. Where the boiler is far removed from the elevator: as in the case of the drainage of colliery workings described in the present paper; with the elevator no attendant need be sent to start it or mind it.

The Chairman observed that the elevator was a very interesting application of one of the most ingenious inventions, and was likely to be particularly useful for special cases in mining districts, where fuel for raising steam was of so little cost, and the great considerations were simplicity of construction and certainty of action without requiring attendance.

Mr. R. Cunliffe said the elevator was not an economical mode of applying steam for raising water, on account of the water being uselessly heated, but was advantageous in particular cases where economy of power was not the object in view, and where the steam was got without cost from heat otherwise wasted. They were now putting up an elevator for a large paper manufactory near Manchester, where warm water was wanted in the top cistern for the supply of the works, and was used afterwards for the boilers, so that the heat would consequently all be made use of. At Messrs. Sharp Stewart and Co.'s works in Manchester they had had an elevator at work two months, supplied with the waste steam from boilers heated by the flues from the forge furnaces; the boilers kept up a supply of steam at night which was not wanted for any other purpose, and had previously to be left to blow off, making a noise that was a nuisance in a town. Another elevator raised the water a height of 36 feet, and its size was No. 7, of 7 millimetres or ·28 inch diameter in the throat, which was rather smaller than the one described in the paper; with 45 lbs. pressure of steam it delivered 340 gallons in 1 hour to the height of 36 feet, and the temperature of the water was raised 30°, from 74° to 104°. In further experiments they had tried it was found that with a No. 25 elevator, of 25 millimetres or 1 inch diameter in the throat, and with 48 lbs. steam, but only partly turned on, the quantity of water raised to the same height of 36 feet was 640 gallons in 8 minutes, equivalent to 4800 gallons per hour; with the steam full on at 46 lbs. pressure, 565 gallons were delivered in $5\frac{1}{2}$ minutes, equivalent to 6160 gallons per hour: the water was heated only 26°, from 58° to 84°, which was the least rise of temperature that had been observed.

From the trials made with the elevator at Kippax Colliery it appeared that about 1 lb. of pressure was required for each foot of elevation, since the water was there raised a height of 27 feet and the elevator stopped working when the pressure fell to about 28 lbs. per square inch. In France he understood they had tried draining some pits in a succession of lifts with different elevators, each taking its supply water from the delivery of the one below; but such a mode of applying the elevator would be even less economical than the

present, because the instrument would not work if the temperature of the supply water were above 160°, and therefore it would be necessary to let the water be cooled previous to the upper lifts, and a great waste of heat would be occasioned.

Mr. W. Haden enquired what was the size of the steam pipe in these experiments with the elevator raising the water 36 feet high; and whether any difficulty was expected in applying the elevator on a larger scale to drainage.

Mr. R. Cunliffe replied that the steam and delivery pipes were both made 3 inches diameter, in order to work the larger elevator of No. 25 size or 1 inch diameter of throat: the diameter of the steam pipe was however found to be too large, and it was therefore replaced by one of $1\frac{1}{2}$ inch diameter, but the delivery pipe was not diminished in size, in order to afford great freedom for the passage of the water. The elevator at Kippax Colliery had only $\frac{3}{8}$ inch diameter of throat, and therefore the $1\frac{1}{2}$ inch steam pipe gave steam enough to work it, notwithstanding the great amount of condensation in the 1000 feet length of pipe. The small pipe had the advantage that there was very little trouble in making the joints steam-tight, compared with pipes of larger diameter. He thought there would not be any difficulty in applying the elevator on an extended scale for drainage where the cost of steam was not a consideration, since there was no limit to the size of the instrument and the steam pressure might be greatly increased for higher lifts.

Mr. Samuel Lloyd asked whether the boiler described in the paper kept up the supply of steam for the elevator constantly, or whether it was liable to be short of steam after a time.

Mr. Wardle said the steam was easily kept up by ordinary firing, and the same boiler also worked the winding engine as well. In this instance it had been a question whether a small pumping engine should be put down to win the few acres of coal left in the colliery, or whether the coal should be lost, as hand pumping was not sufficient to keep out the water; but the elevator afforded the means of getting all the coal out, with the least possible cost of apparatus and without requiring attendance.

The Chairman observed that the economy of the elevator in this case lay simply in its using steam that was not wanted for any other purpose, though the steam might of course be employed in a much more economical way in an engine, if fuel were of any importance.

Mr. C. W. Siemens said that although the injector was very beautiful and economical in action where water had to be raised and also to be heated, as in feeding a boiler, it was remarkably deficient in respect of economy when employed simply as an elevator for raising water, where the water was not required to be heated. This was shown in the experiment which had been mentioned, where the water was raised only 36 feet high in being heated 26°; but the perfect equivalent of heat, as established definitely by Joule's investigations and others subsequent, was that the heat required to raise 1 lb. of water 1° in temperature would raise 1 lb. a height of 772 feet, and 1 lb. heated 26° would raise 1 lb. a height of 772 × 26 or 20,072 feet; hence the economy of the elevator was as 36 to 20,072, or only 1-560th of the theoretical perfect duty of the heat. A very good pumping engine realised 1-6th of the theoretical effect, and ordinary steam engines realised 1-10th to 1-14th, and were consequently 40 to 56 times superior in duty to the elevator. The elevator was therefore economically applicable only where fuel was no object, or as an injector where the heat came in again usefully, as in feeding a steam boiler.

The injector indeed, although inferior to a pump in mere propelling power, he considered the most perfect instrument for feeding boilers, so long as the supply water was cool enough to allow it to work; for then all the heat imparted to the water was returned into the boiler without any waste, whereas in using steam to work a pump the larger part of the heat was wasted by being thrown away with the exhaust steam. The injector however would not be economical if the supply water could be heated by other means free of expense, since its action required the supply water to be kept cool.

The amount of condensation in the long steam pipe mentioned in the paper seemed small for such a length of pipe, and he thought a good deal of water must be carried across the depositing box by the current of steam and pass through into the elevator. He had seen lately in France a simple and efficient contrivance by M. Le Chatelier for

freeing the steam from water, by making the steam pipe from the boiler descend vertically into the depositing box, surrounded by a cylindrical and concentric casing, from the top of which the steam was taken off for the engine; the wet steam rushing into the depositing box in a vertical current carried forward all the water it contained down to the bottom of the box by the velocity imparted to it, while the steam itself turned sharp round the bottom of the steam pipe and ascended through the annular space, passing off dry, and the water was allowed to drain back into the boiler. This apparatus was applied to a boiler which previously consumed 8 lbs. of water per lb. of fuel, and the result was that the consumption was reduced afterwards to only 6 or $6\frac{1}{2}$ lbs. of water real evaporation per lb. of fuel, while the engine went much faster in consequence of having drier steam. But where the steam simply shot across the top of the depositing vessel, as in the apparatus that had been described, he was satisfied that a considerable quantity of water must be lost by being carried across with it.

Mr. E. A. Cowper agreed in thinking that some water would fly across with the steam in the depositing box described in the paper, instead of being separated from the steam. But he thought the best plan would be to superheat the steam at the top of the shaft sufficiently to prevent any condensation taking place in its passage to the elevator: by this means steam might be conveyed to a great distance without loss. He had proposed some time ago to superheat the steam highly above ground at a colliery in the neighbourhood, where a winding engine was wanted in the pit 400 yards from the shaft, and where there was an objection to having the boiler down in the pit, the upcast shaft not being quite large enough for producing the draught for the boiler as well as ventilating the workings: eventually however both boiler and engine were put at the bottom.

The Secretary had seen the elevator at work and witnessed the experiments described in the paper, and could confirm the statements as to its satisfactory working. A uniform pressure of steam was kept up without difficulty; and the elevator started promptly to work in the pit on turning on the steam. The two pressure gauges used at the same time at the boiler and the elevator in the experiments

were afterwards tried both together on the boiler, to check the correspondence of their scales.

Mr. M. Smith asked to what height water could be raised by the elevator.

Mr. R. Cunliffe replied that the height depended on the pressure of steam employed, and the adjustment of the steam and water orifices in the instrument. In the experiments at their works the tank into which the water was raised was only 36 feet above the elevator, and they had not yet had occasion to use the elevator for a greater height. The injector, however, worked up to 150 lbs. pressure per square inch in locomotive boilers, which was equivalent to 300 feet head of water.

Mr. C. W. Siemens thought there must be some imperfection in adjustment of the steam nozzle in the elevator at the colliery, not to get more than 1 foot lift for each lb. of steam pressure.

Mr. Wardle said the elevator was made without any means of adjustment, since economy in first cost of apparatus was the main object to be attained; and the elevator was therefore made of the cheapest possible construction, with the steam and water orifices permanently adjusted to the required sizes for the particular work to be done, but with an excess of steam supply, in order to enable the elevator to keep the pit always clear, even if a larger quantity of drainage water should be met with in the course of the workings.

Mr. E. A. Cowper observed that the proportion of 1 lb. of steam pressure per foot of height was evidently the result of the particular adjustment adopted in the elevator at the colliery; but as the injector would force water into its own boiler, and even into a boiler at a higher pressure than that from which the steam was supplied, the elevator was fully capable in ordinary work of raising the water 2 feet high or more for every lb. of steam pressure, by making the adjustment accordingly.

Mr. H. Woods thought that the elevator would probably be of much service in raising water where large quantities of hot water were wanted, as in breweries. He asked what was the lowest level from which the feed water could be drawn by it.

Mr. R. Cunliffe replied that 5 feet was the lowest level of the feed in their experiments with the injector, but this was dependent

on the quantity of steam used and the temperature of the supply water, for if the water were warm the injector would not draw it from so great a depth.

Mr. J. Tomlinson had found the injector would work when the supply water had to be lifted 5 feet by suction, but stopped if that depth was exceeded even by only an inch or two.

Mr. M. Smith thought in many cases the elevator might be wanted alternately for the two purposes of raising water for filling a tank as an elevator, and also feeding a boiler as an injector: and with suitable means of adjustment and disconnecting there seemed no reason why the same instrument should not be employed in the double capacity.

The Chairman remarked that the application of the injector as an elevator to the drainage of mines opened a very large field for its use; and for supplying blast furnace tuyeres with water it would also be of much value in the iron-making districts. A large quantity of steam was at present wasted under a variety of circumstances, which might be turned to use advantageously by the elevator, without entailing the serious outlay required for pumping machinery.

He proposed a vote of thanks to Mr. Wardle for his paper, which was passed.

The following paper was then read:—

DESCRIPTION OF SELLERS' SCREWING MACHINE.

BY MR. CHARLES P. STEWART, OF MANCHESTER.

The Screwing Machine described in the present paper was designed by Mr. W. Sellers, of Philadelphia, United States, to combine accuracy of cut and greater perfection of thread than is obtained in ordinary screwing machines, with rapidity of action and simplicity of working and with increased facility for keeping the cutting dies in good order. The screw thread is cut in a single operation, and the finished bolt is released by the withdrawal of the dies, the machine being driven continuously in one direction, without reversing or stopping.

The machine is shown in Plates 55 to 57; Fig. 1, Plate 55, is a longitudinal section through all the working parts of the machine, and Fig. 2, Plate 56, an end elevation. Fig. 5, Plate 57, is a longitudinal section of the die box, enlarged to one-third full size; and Fig. 6 is a front elevation of it, with the cover plate removed in order to show the dies.

The dies for cutting the screw thread are in three separate pieces AAA, Fig. 6, Plate 57; these are advanced and held in the required position for screwing the bolt by means of eccentric ribs or cams fixed upon the cover plate, as shown in section at BBB, which work in a notch in the edge of each die, as shown in Figs. 5 and 7. In working, the die box C revolves in the direction of the arrow, being driven from the driving shaft D, Fig. 1, by the pinion E and spur wheel F; and the projecting clutch G on the back of the wheel F carries round with it the cam plate H, which thus revolves at the same speed as the die box C, so that the relative position of the cams and dies remains unaltered in revolving, and the dies are held up to the proper position for cutting the thread without alteration during working.

When the screwing is completed, the bolt is released by the dies being all simultaneously withdrawn by means of the cams: this is effected by the second pinion J, Fig. 1, Plate 55, gearing into the spur wheel K fixed on the shaft of the cam plate H. This pinion J is a little larger in diameter than the driving pinion E, and runs loose on the driving shaft D during the time that the dies are in operation cutting a screw; but when that is completed, the conical friction clutch between the two pinions is caused to engage by pressing forward the handle L, shown dotted in Fig. 1, whereby the spur wheel K being of a little smaller diameter than the wheel F is made to revolve faster than the latter, and causes the cam plate H to overrun the die box C; the dies A, Fig. 6, are thus made relatively to move back along the cams, so that they are withdrawn from the finished bolt, which being released is drawn out by hand, while the machine is still driven continuously in the same direction without stopping or reversing. The handle L on being released is immediately brought back to its original position by means of the counterbalance weight attached to it, thereby disengaging the pinions E and J, and pressing the loose pinion J against a leather collar on the end frame of the machine, the friction of which checks the motion of the pinion J and the spur wheel K of the cam plate, allowing the die box C to overtake the cam plate again; the dies are thus moved forward along the cams till they are again in their original working position ready for cutting a fresh thread.

The adjustment of the dies to the exact position required for the size of bolt to be cut is accomplished by means of a graduated index M, Fig. 2, on the spur wheel F which drives the die box C. The wheel F is loose on the shaft of the die box, and in working is clamped by set screws to the arm N, Figs. 1 and 2, which is keyed on the shaft. For advancing the dies, the arm N is turned forward in the direction of the rotation, as shown by the arrow in Fig. 2, carrying the dies forward along the cams, the latter being held stationary at the time by holding the spur wheel K that is fixed on the cam plate shaft. The dies are thus advanced to the position for cutting, and the spur wheel F is then clamped securely to the arm N by the set screws, having previously been turned so that the projecting clutch G on the

back of the wheel F is engaged with the wheel K of the cam plate. The machine is then ready for starting to work. The total length of the graduated index corresponds with the total length of the cams; and two holes in the wheel F for each of the set screws are sufficient to admit of adjustment throughout the entire range of the index, by means of the slotted arc at each extremity of the arm N.

For changing the dies in the die box, the spur wheel K is turned forward by hand as far as it will move; this brings the dies opposite the openings O in the cam plate H, Figs. 5 and 6, Plate 57. The three fixing screws P are then slacked back till their inner ends are flush with the inside of the cover plate, when the dies can be pushed out through the holes O. In putting in the fresh dies, each die is inserted in turn and pushed down until the notch in its edge comes opposite the fixing screw P, which is known by a shoulder on the screw driver; and the cam plate is worked backward and forward by hand, by means of the wheel K, to make sure of the die being properly placed with the notch fitting on the cam; the fixing screw is then set up, which secures the die from falling out.

In order to cut a full screw thread on the bolt in once running up, the dies are cut with a perfectly full thread throughout, and of such size as to fit the bolt when it has the thread cut complete upon it. The tops of the die threads are then eased off on the side where the bolt enters, as shown at R in Fig. 7, Plate 57, commencing at the base of the thread and terminating at the top of the third or fourth thread from the point of entering. The thread on the bolt is thus formed by a succession of cuts, each one deeper than the preceding, until the full depth is attained.

When the machine is used for tapping nuts, the cutting dies are removed, and the tap holder, shown in Figs. 8 and 9, Plate 57, is inserted in the hollow spindle of the die box, and secured from turning by a blank die, Figs. 10 and 11, which serves as a key fitting into the notch in the tap holder.

The bolt or nut to be screwed is fixed in the sliding holder S, Figs. 1 and 3, Plates 55 and 56, sliding freely on the top edge of the framing; the handle T is made with a finger on it to fit in a rack on

the framing; which gives sufficient leverage for the momentary pressure that has to be put upon the bolt on its first contact with the cutting dies to ensure its entrance. The clamps U for gripping the bolt or nut, shown separate in Fig. 4, are opened or closed simultaneously, one up and the other down, by two right-and-left-handed screws geared together by the pinions V and worked by the hand wheel W. It is essential that the bolt or nut to be screwed should be truly in the axis of the die box, which is ensured by boring the clamps in their places in the machine, and they are afterwards slotted to the required shape.

In cutting new dies or re-cutting old ones, a set of master taps is used; the leading end of the master tap is supported in a circular thimble which slides inside the hollow spindle of the die box. The dies are then pressed close upon the master tap by means of the arm N on the spindle of the die box, Fig. 1, Plate 55, and the machine is run forward and backward; the dies are again closed upon the tap, and the process repeated until a full thread is obtained. A small stop is first inserted in the clutch G between the spur wheels F and K, so as to make them immoveable with respect to each other during the process of cutting the dies.

In this machine the necessity of setting up the dies by hand between successive cuts is obviated, as they are set up at the first by the graduated index of the cam plate to the exact diameter required for the finished bolt, and the screwing is completed in once running the bolt up. With each machine a table is prepared showing the position on the index to which the pointer has to be set for cutting bolts of the various diameters within its range; and a slight change in the position of the pointer will make the bolts slightly larger or smaller, as the case may require. When the dies have become worn and have been re-cut, a readjustment of the index readily gives the means of bringing them up to exactly the same diameter as previously, so that the size of bolt is not altered by re-cutting the dies. The original adjustment of the index is made by actual trial of the different diameters of bolts in the machine, the results being tabulated; and this is done again when the dies are re-cut.

This screwing machine has the advantage of rapidity of action, producing a perfect screw thread in once running up, while the time usually required for running back is saved by the plan of withdrawing the dies and releasing the bolt. The machine is never required to be stopped except for changing or repairing the cutting dies, and does not need the application of a crossed belt or reversing apparatus for driving it, since it runs continuously in one direction only. It is of small size in proportion to the work it accomplishes, and is on a plan very convenient for the workman using it. As the dies can be readily adjusted to any diameter of bolt for which the machine is adapted, they can be worn down for a long time before requiring renewal.

Mr. Cunliffe exhibited one of the screwing machines in working order, and showed its action; also specimens of bolts screwed by the machine, and of the dies used.

The Chairman thought there were many points of interest in the machine, and had not previously seen one in which the entire screwing was done at a single operation without the machine being ever reversed. He enquired how many of the machines were in use and how long they had been at work, and what was the largest size of bolt that had been screwed by them.

Mr. Cunliffe replied that there were a good many of the machines in use in this country besides a considerable number in America, and they had had one at work for three years already at their works. The machine now exhibited was the smallest size made, for screwing bolts up to 1 inch diameter, and the largest sized machine screwed up to 2 inches diameter, as shown by the specimen bolt exhibited of that size: there was also an intermediate size of machine for screwing up to $1\frac{1}{2}$ inch diameter. He showed a set of three di s ·vhich had been in constant use for six months and had

screwed 14,400 bolts of $\frac{7}{8}$ inch diameter, without ever being re-cut by the master tap; they had been faced only twice on the grindstone during the time, like an ordinary chasing tool of a screw-cutting lathe.

Mr. J. Murphy asked what was the cost of the machine, and whether it would cut a square thread as well as an angular one.

Mr. Cunliffe replied that the cost of the machine now shown for screwing bolts up to 1 inch diameter was about £68. They had not yet tried cutting any but an angular thread, but he expected the machine would do as well for a square thread if it were not too large for a single cut. The machine had a great advantage in rapidity of work by completing the screw at one cut: in the ordinary screwing machines the screw had to be run up three times to make a good thread, which with three times of withdrawing made six times altogether for the screw to pass through the machine, instead of once only in the new machine; in addition the time of stopping and reversing the ordinary machines was entirely saved in the new one, the machine running constantly in the same direction.

Mr. D. Joy enquired how many bolts would be screwed in a day by the machine, of $\frac{3}{4}$ inch diameter and screwed for a length of $1\frac{1}{4}$ inch. He had known 500 made per day of $10\frac{1}{2}$ hours, with a common screwing machine in which the dies were withdrawn for drawing back the bolt, when working as fast as possible. He asked also whether any difficulty was experienced from stripping the thread in cutting, when the cutting was completed by running once up the screw.

Mr. Cunliffe replied that he had never seen the thread stripped in any of the bolts, and the dies gave a clean cut like a chasing tool in a lathe, as shown by the specimens of bolts exhibited. The machine cut 92 screws per hour or about 960 per day of $10\frac{1}{2}$ hours in screwing $\frac{3}{4}$ inch bolts through $1\frac{3}{8}$ inch length.

Mr. D. Joy enquired whether the machine was run round by hand in re-cutting the dies by the master tap, in order to allow of working it backwards and forwards.

Mr. Cunliffe replied that a crossed strap was used at the time of cutting or re-cutting the dies, for the purpose of reversing the machine, but was required only on those occasions.

Mr. E. A. Cowper observed that there was a limit to the capability of cutting a thread by once running up in the machine, depending on the quality of iron that was being screwed: with a large thread the iron would give way and would not stand the extreme strain of cutting up the whole thread at once, unless it were of an unusually close and fine texture. He noticed that though the small bolts showed a good clean thread, the large bolt of 2 inches diameter had the thread ragged in several places. Probably in practice the large bolts would be run up two or three times to make a good thread. Bell-mouthed dies as used in the machine prevented the thread from being run up of the full depth right to the head of the bolt, but this was perhaps of little consequence in the general make of bolts.

Mr. J. Tomlinson thought that the new machine had the objections of the old ones with solid dies, and was much more complicated in construction, the only advantages being that the separate dies could be readily sharpened up, and the fact that the bolt could be released without running the machine back; but he thought it questionable whether even these advantages would compensate for the increased cost of the machine itself, and it appeared to him not equal to machines now in use in which bolts varying slightly in diameter could readily be cut. The differential motion of the cam plate and die box was certainly an ingenious contrivance.

Mr. J. Murphy asked whether different diameters of bolts could be screwed with the same dies.

Mr. Cunliffe replied that this might be done to some extent, but it would be at a sacrifice of the quality of the thread cut, owing to the cutting threads on the dies being in that case at a slightly different angle to the thread on the bolt they were cutting. To ensure a full and true thread, bolts should be cut only with dies made specially to suit their diameters.

The sliding holder was required to hold the bolt perfectly true in the centre line of the dies in order to ensure accuracy of work, and this was accomplished by making the machine bore its own hole in the holding clamps while in their places, and they were afterwards slotted out square, with witnesses of the boring left in to ensure strict accuracy.

The Chairman moved a vote of thanks to Mr. Stewart for the paper and the numerous specimens exhibited, and also to Mr. Cunliffe, which was passed.

The Meeting then terminated.
